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The Coral Reefs of Arno Atoll, Marshall Islands

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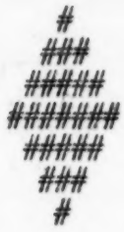
THE CORAL REEFS OF ARNO ATOLL,

MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA - Pacific Science Board



An atoll has a top that's flat
And featureless extremely.
Corals and algae make a mat
Where mountains are not seemly.

(R.H.F., 1949)

John W. Wells, assisted
by Donald F. Squires
Cornell University
1 November 1950

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I. Field Work

A. Reefs

The coral reefs were the main object of study during the field period, and all types of reefs represented at Arno were investigated in some detail:

Ine Island - Seaward-leeward reef; windward- lagoon reef. A three-mile stretch on either side of Ine Village was mapped in detail on a scale of 1:8000 (see figures).

Takleb Island - Seaward-windward reef; leeward lagoon reef. Mapped.

Aotle and associated islets - Seaward-windward reef; lagoon reef. Mapped.

East Horn (Malel to Lonar I.) - Seaward-windward reef; lagoon reef (enclosed lagoon). Mapped.

North Horn (Eneman-Bikarej-Namwi) - Seaward-windward reef; seaward-leeward reef; enclosed lagoon reef; reef "dam" at north end. Mapped.

Studies were made of the water temperature fluctuations on the reef tract on the seaward side of Ine Village.

B. Lagoon

Following the arrival on 19 July of dredging gear from Washington, dredging was carried out nearly every day until 1 August, when the gear was re-packed for shipment. Earlier attempts to dredge with a crude dredge made from material at hand were described in the first field report. The regular dredges were more successful, but the great difficulties in operating from sailing outrigger canoes further emphasize the

point previously made that systematic dredging, a necessary part of any scientific study of an atoll, is possible only from a sizeable powered boat. Nevertheless, as a result of Mr. Squires' persistence, a number of bottom samples and zoological specimens were obtained from some 25 hauls in the lagoon, even though nearly half of them were dry runs.

C. Collections

Corals. About 600 specimens, mostly cured, of reef and lagoon corals were collected and packed for shipment.

Other. Insofar as possible, with only 2 gallons of alcohol, specimens of mollusca, echinoderms, alcyonarians, foraminifera, crustaceans, etc., were collected for the U. S. National Museum, as well as some dried material. A number of specimens were preserved but later had to be discarded or dried because of lack of sufficient preservative. Ten gallons of alcohol requested from Majuro late in June was finally delivered at Majuro on the return journey. Some was added to the one tank, but the rest by that time was of no use and was returned.

In all 18 wooden packing cases were filled, weighing about 1000 pounds and shipped back by surface transport. They have not yet been received but should arrive before the first of November. This was impossible, but makes it impossible to list in this report the coral species, some of them probably new, collected. It is estimated that over 100 species representing about 40 genera of scleractinian and hydrozoan corals were procured, with ecological data.

About 350 photographs (Kodachrome) were taken, mostly of reef phenomena, including a number of underwater views. Five hundred feet of 16-mm. color motion picture film were exposed, again mostly of reef

features above and below water, with unexpectedly good results. The motion picture camera and tripod were a loan from the Navy through the Honolulu office of the Pacific Science Board, and grateful acknowledgment of this is here made.

II. Preliminary Analysis of the Reefs

A. General Statement

Arno Atoll, in the southern Marshall Islands at approximately 172 deg. E. and 7 deg. N., lies in the northeast trade wind belt and in the north equatorial current. The latter is deflected northwards during the summer months by the equatorial counter current. It is that part of the Pacific where the surface water temperatures do not fluctuate more than 1 deg. above or below 28 deg. C. - the warmest part of the Pacific. The temperature, clarity, and agitation of the surface are at the optimum for reef coral development, but the planktonic food supply, on the other hand, despite the seasonal reversal of oceanic currents, is lower than in areas farther to the southwest and coral growth is below the maximum.

Arno, like many atolls, departs from the common idea of circular atoll shape, being roughly rectangular with two extensions or "horns", one extending to the north about 5 miles from the north corner of the rectangle ("North Horn"). The other extends about 7 miles northeastward from the east corner ("East Horn") (Figs. 1 and 2). Both horns are peculiar in that each encloses near its tip a small secondary lagoon separated from the main atoll lagoon. The total area enclosed by the seaward reefs and lagoons is about 147 sq. mi. The surface reefs cover about 16 sq. mi. and on them 80-odd islands and islets form about 5 sq.

mi. of dry land. The main lagoon encloses about 125 sq. mi., the secondary lagoon in the East Horn about 4.5 sq. mi., while the little enclosed lagoon of the North Horn has an area of only 1.5 sq. mi. The seaward reefs extend continuously around the entire atoll, except where they are broken by Tutu and Yakleb Passes, which have threshold depths (15-25 fms.) nearly equal to the lagoon depth, three shallow (4 fms or less) passes east from Takleb and one shallow pass into the northwest part of the East Horn lagoon. The total peripheral extent of the seaward reefs is about 63 miles, and except for the minor pass into the East Horn lagoon, all breaks in the reef are in the 6-mile windward stretch of the northeastern face of the atoll extending southeasterly from Tutu Pass toward Namej Island.

The beaches of the seaward sides of the atoll are everywhere bordered, with very few exceptions such as Ine Anchorage and stretches of low reef tract on which islands are not yet developed, by boulder ramparts rising from 3 to 10 feet above high tide level. This boulder ridge may slope gently lagoonward and constitute the main mass of an island, but on the southern side of the atoll where the lagoon side is unsheltered from the wind, it grades into gravel and sand, the latter blown inward from the sand beach along the lagoon. For long stretches in this area the supply of sand is sufficient to enable the wind to develop long low dune ridges at the top of the lagoon beach, in some places to a height of 10-14 feet.

Between low and high tide levels on lagoon and seaward sides beach sandstone and conglomerate ("beach rock") is often developed after the manner described for many atolls and other reef tracts. Exposed stretches

of beach rock outward from the present beach line indicate horizontal shifts of the strand. In places these changes are attributable to the effects of the rare but violent typhoons from the south, most recently in 1905 and again in 1918. Great changes were effected by both of these (but native memories are vague in terms of <u>just when</u>) along the whole southeastern seaward shore from Lonar to the eastern tip of Ine. According to the natives this entire section, now broken up into many islands, was previously a continuous land strip. This is confirmed by the chart of the atoll published by Agassiz (M.C.Z.Mem.,xxviii,pl.228, fig.4, 1903), and direct evidence is found in the beach rock ridges now extending along the lagoon side of the reef tract from Lonar to Kilane (Fig.6), and elsewhere.

Not all exposures of beach rock, however, are due to typhoons or other storms. Short exposures of beach rock on the lagoon side of Ine Island westward from Ine Village for several miles alternate with long stretches of sand beach beneath which beach rock is now developing. In places active erosion and undercutting of the beach is now producing new beach rock exposures, while in others aggradation is covering older beach rocks. It appears that this southerly lagoon side is not wholly stabilized, and that shifting waves and currents add here and subtract there, with little net loss or gain.

At no place on the atoll is there evidence of any recent vertical shifts in the strand line, supposed to be so widespread in the Pacific area.

The seaward slopes (Fig.3) of the outer reefs are steeper on the leeward than on the windward sides. No precise data are available, but

it is obvious from an inspection of aerial photographs of Arno, and indicated by H.O. Chart 6005, that there is a decided difference. At Ine Anchorage a depth of 200 meters is reached about 150 meters out from the reef margin, a slope angle of 55 deg. At 1700 meters the depth is 1000 meters, about 27 deg. Thus the profile from reef edge seaward is concave, and steeper near the reefs, gentler with increasing depth. On the seaward side off Takleb Island the depth 400 meters out from the reef edge is only 40 meters, a 7 deg. slope. In the next 350 meters the depth increases to 200 meters, a slope of 25 deg., nearly the same as the downward slope from 200 meters on the leeward side. At 3500 meters from the reef margin a depth of 1000 meters is reached, a slope of 19 deg. from 750 meters. This slope is essentially convex near the reefs, thence gently concave. The presence or absence of a 10-fathom terrace like that at Bikini is not determined, but comparison of aerial photographs of corresponding parts of the two atolls suggests strongly that it is developed on the windward side of Arno.

B. Reef Types

The seaward reef types at Bikini Atoll in the Northern Marshalls were recently classified by Tracey, Ladd, and Hoffmeister (G.S.A.Bull., lix,p.870,1948), largely on the basis of the character of the reef margins, as follows:

I. Strongly grooved

A. Lithothamnion ridge low, uncut by the grooves.

B. Lithothamnion ridge prominent, cut by grooves.

1. Room and pillar structure developed.
2. Algal mounds and blowholes developed

II. Grooves weak or absent

A. Margin smoothly scalloped

B. Margins made irregular by erosion.
(two subtypes)

The distribution of these types at Bikini is shown on Figure 3 of the paper cited. Application of this classification to the Arno reefs is shown in Figure 2 of this report (and to some extent on the detail maps, Figs.4,5,6,7,8). Comparison of the two shows one striking difference and a number of similarities. The difference is the almost complete absence of reefs of Type II, in which the grooves down the upper part of the slope are weak or absent, at Arno, whereas at Bikini they are characteristic of the leeward stretches. According to Tracey, Ladd, and Hoffmeister, where reefs of this type are developed there is no evidence of a terrace. At Arno there is no evidence of a terrace on the leeward slopes, but a strongly grooved, steeply sloping reef margin of Type IA, with low algal ridge, is developed. A typical profile of such a leeward reef of this type at Arno is shown in Fig. 9.

Reefs of Type IB_2, with strongly developed algal ridge, are found at corresponding windward sites at both atolls, alternating with Type 1A which is developed on stretches less exposed to the northeasterly and easterly trades. At Arno there does not appear to be the close relation between islands and Type IB reefs and stretches between islands and Type IA, observed at Bikini. In areas where there are islands or islets on the reef, open spaces between islands are narrow and water flow across the flat is impeded by rubble.

At only one site at Arno is a reef of Type II (grooves weak or absent) developed. A stretch of about 300 meters northwestward from Stony Point on the seaward leeward side at Ine Anchorage in a shallow bay between two crescentiform swellings of Ine Island best fits Type IIA. Grooves are absent and the margin slopes very steeply, practically vertically at first, less so below about 10 meters, with an average slope of 55 deg. to 200 meters. There are more or less regular re-entrants 3 to 10 meters deep, 2 to 10 meters wide, with sandy or rocky floors. One or two of these are interconnected by open channels, isolating flat-topped pillars, but there is no evidence of collapse due to erosion. Wind waves are negligible at this site and the strong swells from the east are reduced by the projection of Stony Point.

C. Lagoon Reefs

The lagoon reefs are not so continuously developed as the seaward reefs although banks on which reefs might exist are continuous. They are best developed along the windward lagoon side of the west, south, and north sides, where there is little or no wash of sand and other detritus from the seaward reefs. The only development of leeward lagoon reefs on the windward side of the atoll is in the vicinity of the two threshold passes, Tutu and Takleb. The sand banks developed on the lagoon side of the windward reefs from wash from these reefs are rapidly extending into the lagoon. They slope steeply downward toward the lagoon floor at about 35 deg., the normal angle of repose.

In the enclosed lagoons of the North and East Horns the reefs are distributed as in the main lagoon but again coral growth is patchy owing to the sand cover of the flats and lagoon slopes.

In the North Horn (Fig.4), which has no pass whatever to seaward a special situation has developed. On all sides except the north, the seaward reef flats are built up either with islands or thick rubble to a level above low tide level. On the eastern side the rubble areas between islands are penetrated by sand-floored channels from the lagoon side, usually with a moderately rich growth of corals, but about halfway to the seaward margin they become very shoal and choked by rubble which often is more or less cemented. Except to the north this rim is 1 to 2 feet above low tide level, but is 2 to 3 feet below high tide level. When tide level falls below the rim level the excess water flows northward and part of it escapes over the lower rim between the ends of the windward and leeward reefs. The rest of it flows outward through the channels onto the seaward reef flats. Formerly most of the excess flowed out by the northern outlet, which was covered or crossed by a reef flat built to within about a foot of low tide level. This rapidly moving water, however, supported a profuse growth of corals and calcareous algae which have now grown up across the opening, forming a low, broad, convex rampart, one edge of which slopes steeply into the lagoon, the other gently down into the scattered microatolls around the embayment in the northern end of the horn. At present this dam has a uniform crest of at least 2 feet above low tide level on the seaward side, and over its entire surface there is a steady but diminishing outflow of water as the tide ebbs. Coral growth is rich but the depth of water on the spillway slope at each low tide is now hardly more than an inch and broad stretches are exposed, and coral colonies are low and spreading.

Thus the water level in the enclosed North Horn lagoon never falls as low as the level reached at low tide on the seaward reefs.

This enclosed North Horn lagoon is much shallower than the main lagoon or the enclosed East Horn lagoon, and soundings shown on the H.O. chart indicate a maximum depth of 10 fathoms. Coral knolls are numerous, and the lagoon is probably filling rather rapidly. Because of the absence of even a shallow pass into this lagoon circulation of the lower levels of water in it must be restricted, but unfortunately it was not possible to obtain bottom samples bearing on this point.

D. Coral Knolls.

These characteristic structures of atoll lagoons, often loosely referred to as "coral heads", are abundant in all the Arno lagoons (Figure 1 shows only a very few of the knolls). Some of them are sufficiently developed as to be awash or even exposed 2 to 4 feet at low tide. In the main lagoon there are six areas where they are concentrated: 1) in the area at the base of the North Horn generally west of Eneweto Island, 2) a large cluster fanning out from the break in the reef south of Jarkul Island, 3) across the inner end of Tutu Pass, 4) halfway across the lagoon between Takleb Pass and Ine Village, 5) in the southeast corner of the lagoon, and 6) in the secondary embayment at the base of the East Horn.

The distribution of the knoll clusters seems less than fortuitous. Three are in corners of the lagoon, and two are associated with threshold passes. The remaining one, the large Jarkul cluster, is probably also of the second group. The broad break in the reef southeast of Jarkul (2 miles northwest of Tutu I.) suggests a filled-in threshold pass. The

absence of a strong seaward reef at this point still enables the wind waves and swells to sweep in and transport large quantities of sand which are building a "delta" into the lagoon over the site of the former pass. Around this "delta", within a radius of about 1.25 miles there are at least 65 knolls visible on aerial photographs in addition to two large shoals. The cluster around Tutu Pass is smaller - 22 - and none is visible in the immediate vicinity of Takleb Pass. The latter is shallower than Tutu and less to windward, but the large cluster in the lagoon to the south, beginning about a mile from the pass, may be related to it. Are these knoll clusters related to the developmental stage of the passes with which they are associated?

A somewhat similar distribution of knolls may be found in the lagoon of Majuro Atoll, suggesting an interesting minor research problem.

III. Reef Zonation

A. Seaward Reefs

As indicated above, three reef types of the Tracey-Ladd-Hoffmeister classification are developed at Arno: IA, IB, and IIA.

1. Type IA.

This is the dominant type at Arno, and extends almost uninterruptedly from the west side of the North Horn southward around the lee side of the atoll to the eastern end of the East Horn. A typical section of this type of reef, strongly grooved with a low algal ridge uncut by the grooves, is shown in Figure 9. The broad rock flat, seemingly barren, supports no coral growth except in occasional depressions where small patches of Porites lichen and a few other forms grow feebly. At practically all sites, however, except on open stretches unbroken by development

of islands (i.e., NE of Kilomon, E. of Takleb), there is an extensive overgrowth of a curly, disreputable-looking brown alga on the fronds of which live vast numbers of Calcarina. Associated with these are many individuals of the large, closely-adherent pelecypod Chama which resemble projections of rock about the size of one's fist. This is the Calcarina-Chama zone. This zone is truly barren only where there are prominent convexities in the reef (Fig.8). Where this flat begins to slope gently down as the "algal ridge" toward the upper ends of the grooves, low and broadly adherent colonies of Pocillopora are usually dominant, (with fewer specimens of Acropora, Astreopora, Porites, etc.), on the weak encrustation of lithothamnion,- the Pocillopora zone, at the outer end of the waves of translation at low tide. Beyond this, in the surf zone, Pocillopora is replaced by Acropora (A. pectinata, A. digitifera, etc.), forming a zone extending well down into the upper part of the grooved area. Other common genera in the Acropora zone are: Astreopora, Porites, Millepora, Favites, etc.

2. Type IB

This seaward reef type, with relatively high, prominent algal ridge, is characteristic of the exposed windward reef tracts, and is replaced by Type IA only where some protection is afforded by concavities in the reef margin. The usual zonation of this type is shown in the section, Figure 10. The rocky flat is usually less richly endowed with the alga-Calcarina-Chama association and the ridge is not a place of vigorous coral growth (Fig.5). The surge channels are usually shallow, rarely roofed over, and often partly filled with coarse boulders. Occasional small colonies of Acropora cuneata are found, but less commonly than in

the corresponding zone on reefs of this type at Bikini. Nowhere is this reef as broad as at Bikini, and no trace of an inner Heliopora zone was noted.

3. Type IIA.

As previously noted, this type is found only in a limited area at Ine Anchorage (Fig.8). It is distinctly zoned by corals as shown in the section, Figure 11. Following an inner barren zone, exposed for long periods at practically every low tide, is a broad tract thickly settled by extensive colonies of Montipora ramosa,- a nearly exclusive society, here and there replaced by patches of Acropora hebes or alcyoniid "soft corals". Occasional colonies of Synaraea, Leptastrea, Porites (especically P. superfusa), and Pavona, also occur. At low tide the depth is from zero to about fifteen inches, and the water is practically undisturbed by swells or waves of translation. The outer limit of this zone is at about the inner extent of the ordinary low tide waves of translation, where it is succeeded by a zone dominated by Acropora, espedally species of the corymbose A. pectinata type, which extends to the reef margin. Fungia scutaria is common in this zone. It is the zone of richest variety of corals and other reef animals. Calcareous algae are relatively very unimportant. Species of at least 33 genera of scleractinians and hyrdozoans have been collected in the zone, but Acropora accounts for around 90% of all colonies. Over the reef edge and in the re-entrants along the edge the next zone, marked by the pedestal colonies of A. reticulata, begins about 6 feet below low tide level in water only slightly agitated by the constant but low swells, and extends down to about 30 feet,

where coral growth becomes very sparse. Fungia scutaria and other species of this genus are very common.

B. Lagoon Reefs

Two main types of lagoon reefs may be distinguished at Arno. One is found on the leeward side of reef tracts on the windward side of the atoll, or on the leeward side on long stretches where islands are not yet developed. The other is developed on the windward side of the island-flecked reef tract on the leeward side of the atoll.

1. Leeward Type

The first type is developed in the enclosed lagoons of the North and East Horns (Fig.13), and in places along the sheltered leeward side of the reef tract between the horns (Fig.12). The immediate substratum is primarily the sand washed into the lagoon margin from the outer reefs, either across the flats or around the passes. These sand tracts slope steeply (35 deg.) at their inner edges, which may be from a very few to several hundred feet out from the shore, down to the lagoon floor. On this insecure base luxuriant coral patches are scatteringly developed, rising with more or less abrupt sides from depths of a foot or so, often very close to the beach, to 12 or 15 feet. The spaces between them are flat and floored with sand on which few corals grow. The characteristic coral of this zone is Porites andrewsi, a ramose form found in the same environment at Bikini and other northern Marshall atolls. Also common in this zone is Acropora palifera which often forms huge colonies in shallower parts of the sandy interspaces. Fungia is common. The Acropora reticulata zone, found below about 6 feet down on the Type IIA seaward reef, extends

as might be expected on these protected lagoon reefs well into the P. andrewsi zone, in as little as 2 or 3 feet of water at low tide. It does not appear to extend downward much below about 20 feet.

The second type of lagoon reef at Arno, exemplified by the section, Figure 14, extends from near the southeastern corner of the lagoon along the windward southern side of the lagoon the entire length of Ine Island to Arno Island, about 13 miles, and beyond. It is the broadest of Arno reefs of any type, averaging about 1500 feet from beach to margin. The flat consists of a patchy veneer of sand and silt on an uneven, corroded reef rock flat which lies from 6 inches to 3 feet below low tide level. It is shallower near shore, deepening to about 3 feet at the midpoint, then shoaling near the margin, which in a few places is exposed at low tide, Beyond this low ridge the rock surface, often quite bare of sediment, slopes gently at about 10 deg. to the sandy floor of the lagoon at 15 or 20 fathoms. Coral growth over this type of reef is sporadic and nowhere rich and flourishing. The width and depth of the tract enable the wind waves to proceed well in toward shore where they keep the sand and silt well stirred at high tide, inhibiting the growth of all but a few colonies of such hardy forms as Porites lutea and Pocillopora damicornis. Hippopus is common in this inner zone. In the deeper water beyond and nearly to the margin, Astreopora is abundant, forming massive heads up to 5 feet across. Many large dead colonies of Acropora palifera and A. gemmifera, occasional large Pocillopora, and discouraged Porites andrewsi also occur. On the bare, pitted and irregular marginal slope is found the widest variety of forms, but no one species appears dominant. Especially common are several species of soft alcyoniid corals. Fungia is

absent. Lithothamnion is only occasional and not flourishing. From a depth of about 5 feet down the slope, Acropora reticulata is dominant, often forming huge spreading brackets 3 to 8 feet across. This zone extends nearly to the lagoon floor into the Acropora formosa habitat.

A third type of lagoon reef, with an algal ridge and zonation similar to that of seaward reefs, is developed at Bikini around the western end of the lagoon, where wind waves developed over a fetch of about 20 miles produce a strong surf. This type is not found at Arno where nowhere do prevailing winds have a fetch of more than 10 miles.

IV. Reef Temperatures

For mid-Pacific reefs there is, so far as the writer is aware, only one detailed record of water temperature variations across a definite reef tract. In 1918, A. G. Mayer published (Carnegie Inst.Wash., Pub. 213, pp.31-34, fig.9) an account of the temperatures on the Murray Island coral reef, Torres Straits,- a fringing reef about 1800 feet wide. In general he showed that while daily temperature changes at the seaward margin have a narrow range (3.5 deg.C.), the range increases toward shore to as much as 12.5 deg. (C.), and concluded that the high temperatures experienced during part of the year must be sufficient to kill all corals within 450 feet of the shore.

During the month of June, 1950, a number of temperature traverses were made across the Ine Anchorage Reef along the section line of Fig. 11, at various times of day and states of tide. The temperatures were measured at the height of coral growth, usually about a foot from the bottom, at 30-foot intervals across the 450-foot width of the reef.

The results are summarized in the chart, Figure 15, and presented in the same form as Mayer's cited above. On the basis of Mayer's results and theoretical considerations, the results obtained at Arno might have been predicted. The least range is found at the seaward edge, the greatest nearest shore, regardless of the state of the tide. Coral growth on the reef is closely correlated with this. It is richest at the reef margin where the temperatures are more constant, and weakest or absent near shore where temperature ranges are greatest. This correlation, of course, is not exclusively due to temperature control. Agitation and water movements are greatest near the edge; salinity fluctuations due to heavy rainfall are greatest in the very shallow water near shore, among other controlling factors.

The fluctuation is diurnal. Early in the morning, before the sun shines on the reef flat, temperatures across the reef are nearly uniform, usually a degree less nearer shore than the normal 28 deg. C. at the reef margin, but within a few hours temperatures near shore, even at high tide, are much higher than at the margin.

Of particular interest is the two sets of serial temperatures graphically analyzed in Figure 16. These were run at 50-foot intervals along a line 1000 feet long and parallel to the reef edge and about 200 feet from shore, approximately on the boundary between the Acropora and Montipora zones. At the east end this line cuts across the transverse section line of serial temperatures shown in Figure 15. At high tide (10:30 a.m., 24 June) the water along this line was about 3-4 feet deep, and little variation in temperature was expected or found. With this depth of water the swells are little impeded and broken by the reef

margin and no cause for fluctuation is developed. But at low tide (4:00 p.m., 23 June) great variation was found: from 28.2 to 30.9 deg. at more or less regular intervals along the tract. The highs were about 200 feet apart and alternated with the lows. These represent wedges of cooler water extending into the shoreward band of warmer water, or contrariwise. The separation of these wedges is striking. At one spot a temperature difference of 1.5 deg. was found in a distance of only 25 feet.

The explanation of these wedges of warm and cool water at low tide is not hard to find. There is a close correlation between the wedges and the re-entrant channels in the reef margin. The cooler water wedges are opposite the re-entrants, the warmer wedges extend outward opposite the salients. At low tide the constant swells from the southeast, refracted around the easterly side of the atoll from the northeast, are slowed by the salients but move undiminished into the re-entrants. A wave of translation forms at the head of a re-entrant and is reinforced by refracted swells from the salient on either side. This drives a mass of cooler water onto the reef flat at each re-entrant. Rip currents moving outward onto the salients then shift the displaced warmer water toward the salients.

V. AAppendix: List of Coral Genera Occurring at Arno

A. Scleractinia

1. Acanthastrea
2. Acropora
3. Alveopora
4. Anacropora
5. Astreopora
6. Coscinaraea
7. Culicia
8. Cyphastrea
9. Echinopora
10. Favia
11. Favites
12. Fungia
13. Goniastrea
14. Goniopora
15. Halomitra
16. Herpolitha
17. Hydnophora
18. Leptastrea
19. Leptoseris
20. Leptoria
21. Lobophyllia
22. Merulina
23. Montipora
24. Mycedium
25. Pavona
26. " (Polyastra)
27. " (Pseudocolumnastraea)
28. Platygyra
29. Plesiastrea
30. Pocillopora
31. Porites
32. " (Synaraea)
33. Psammocora
34. Seriatopora
35. Stylocoeniella
36. Stylophora
37. Symphyllia
38. Ulophyllia

B. Alcyonaria

1. Heliopora
2. Tubipora

C. Hydrozoa

1. Distichopora
2. Millepora
3. Stylaster

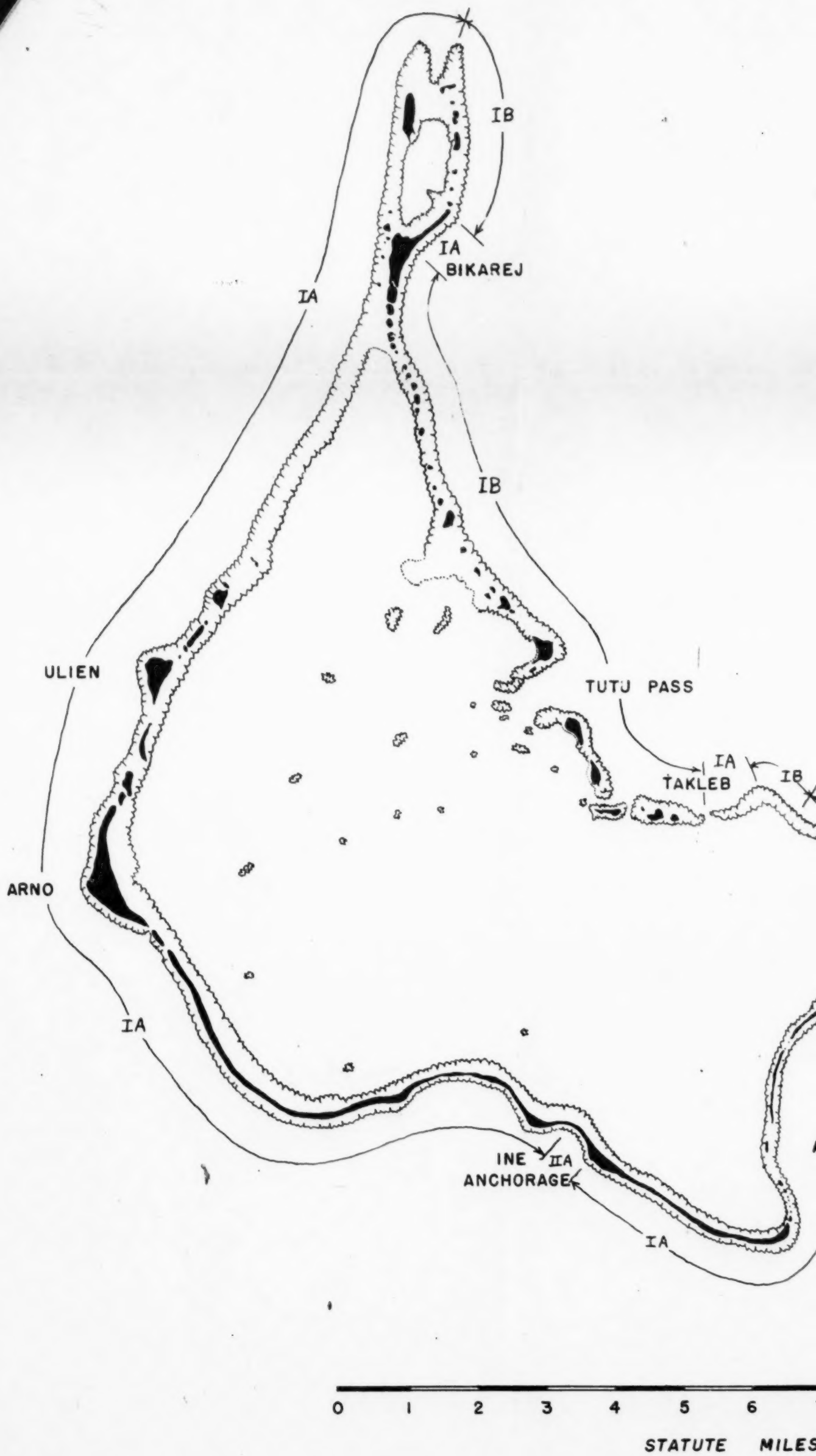


FIGURE I. DISTRIBUTION OF R

N

IB

IA

LŌNAR

IB

IB

IA

IA

MALEL

IJOEN

IA

AOTLE

7° N.

172° E.

7 8 9 10 11 12

LES

REEF TYPES, ARNO.

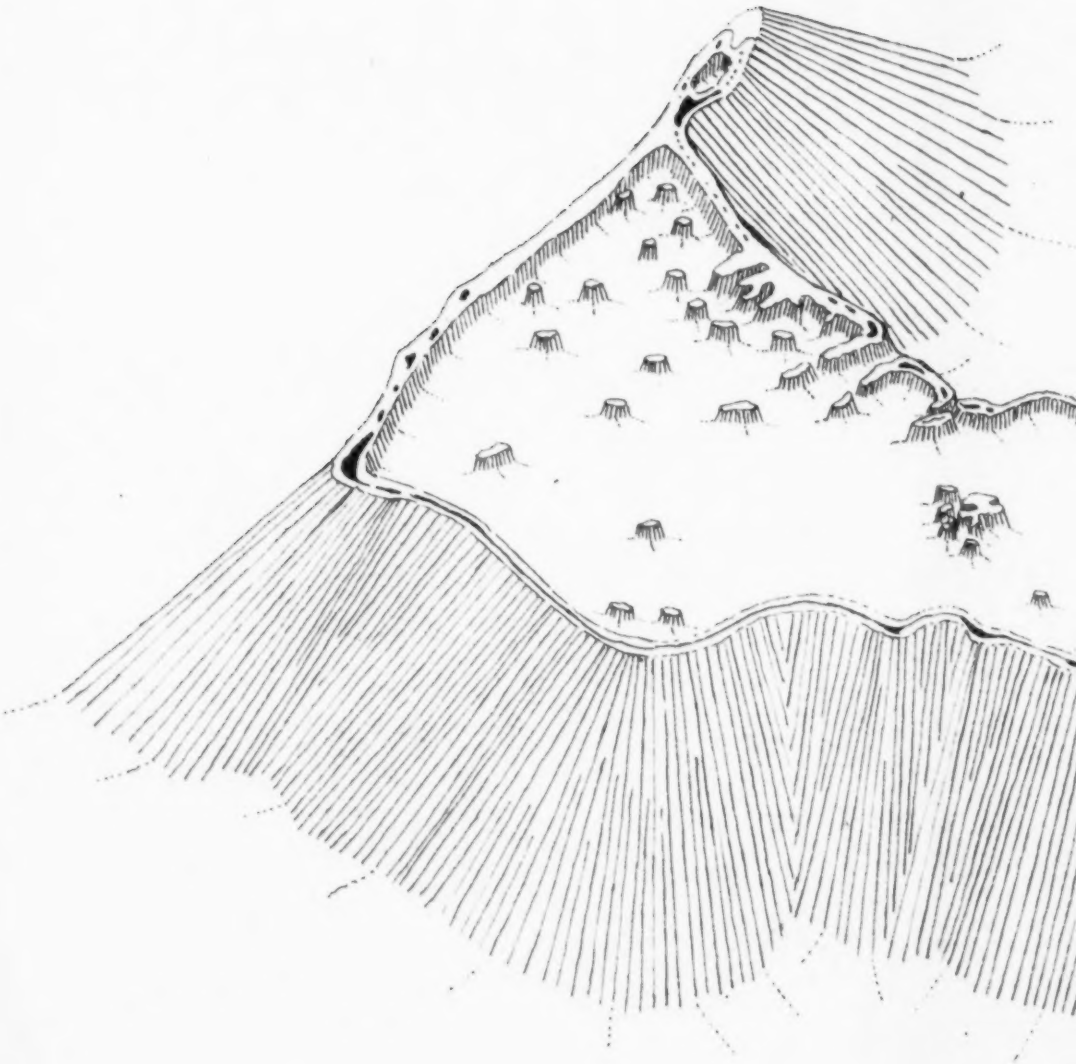
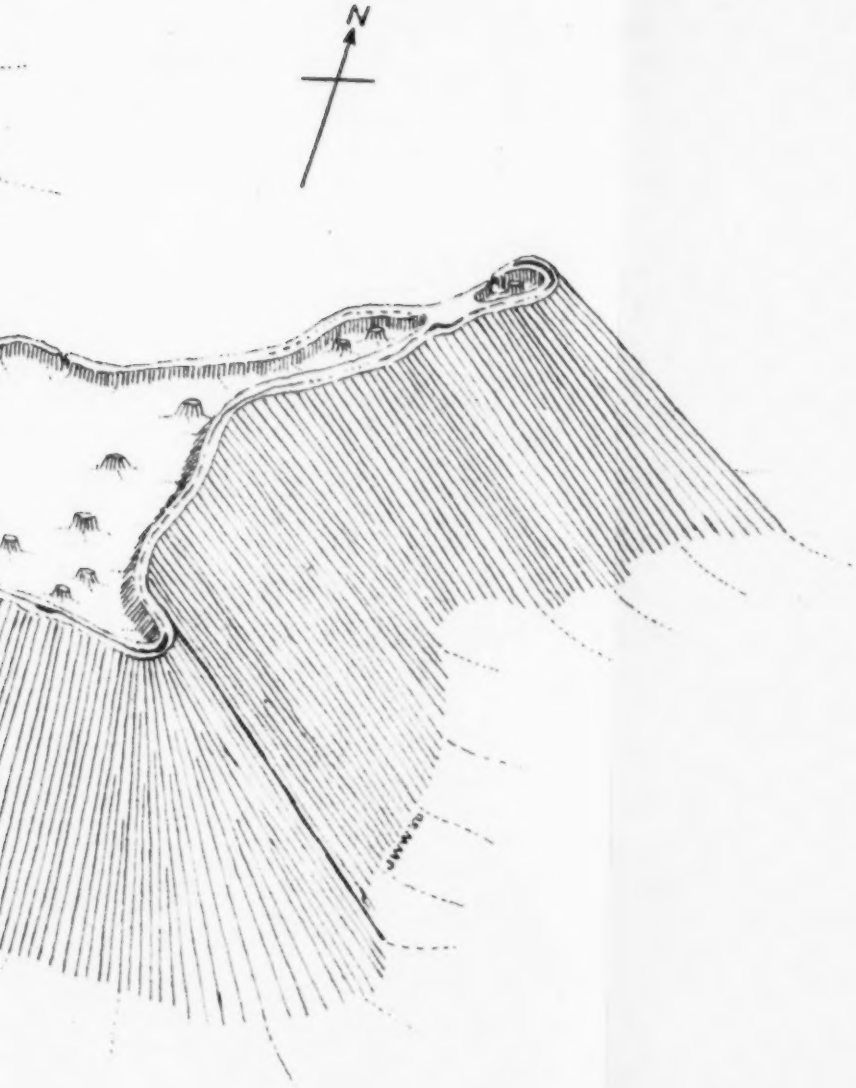


FIGURE 2. PHYSIOGRAPHIC DIAGRAM,



ARNO ATOLL.

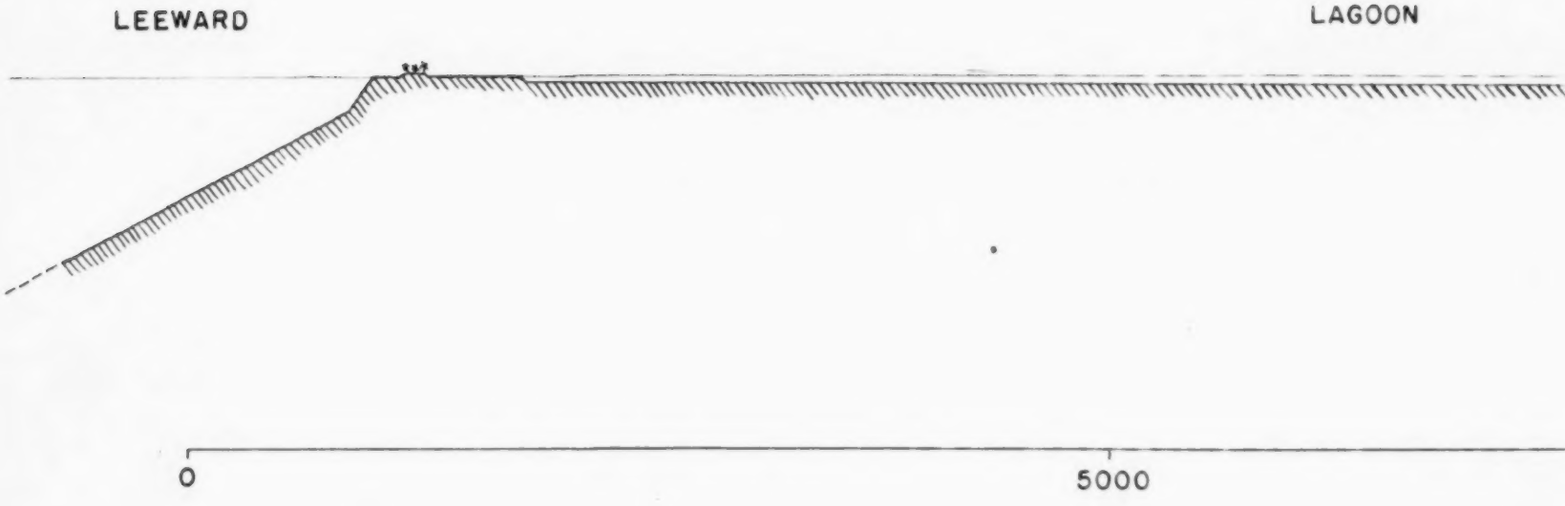
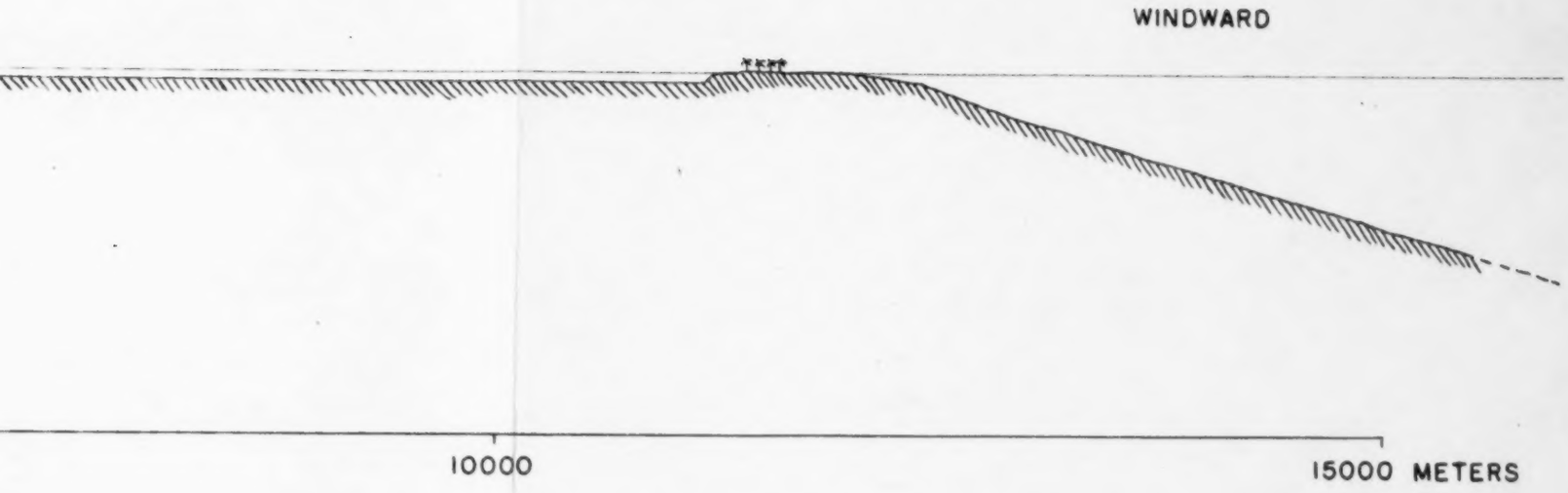


FIGURE 3. TRUE SCALE CROSS SECTI



CTION, ARNO ATOLL.

Lojorñak
Bokan Kouk
Mohmak
Bikōn Mao
A. palifera Channel
Coral - Algal Dam
Mixed Microatolls
Occasional Corals
NAMWI
P. andrewsi
Acropora digitifera - Heliopora - F. lichen
Sloping Algal Platform

Sand Flat
No Corals
(North Exposed at L.T.)
Ile Ienne
Bokan
Bokan Tak
Bikonele
Sand Flat
Mixed
Micro
Channels
Channels
Reef Flat
Reef Flat
Reef Flat
Coast
Algal Flats
Old Lagoon Floor
Lagoon Channel
Lagoon
Lagoon
Lagoon

N

Mud

Binarej

Old Chank Flat

Bikonele

Pavan Chan

Liprijen

Bokiclaj

Rakiaer

Nalimadrik

Enentiwol

Baldbaren

Holothurian Channel

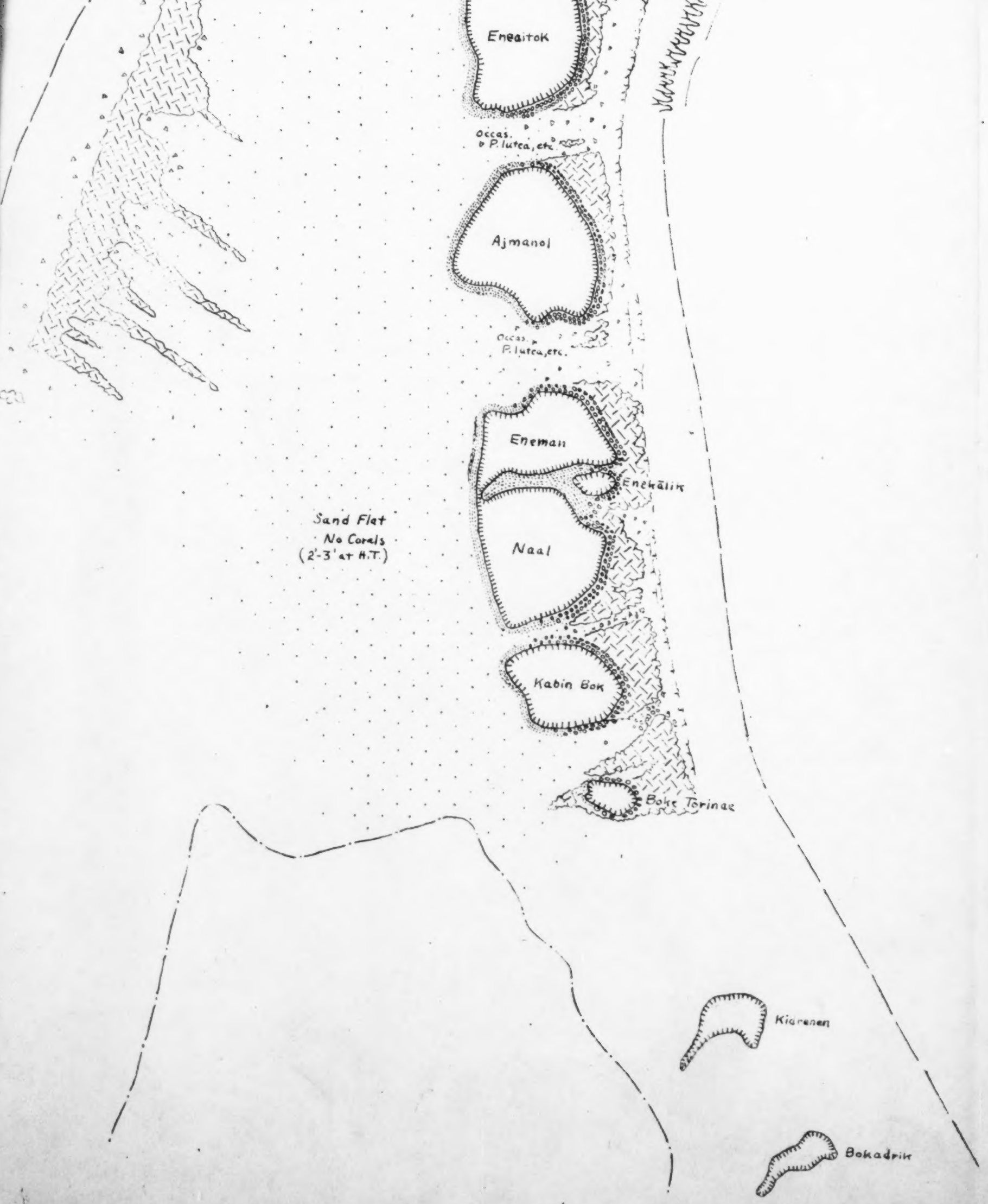
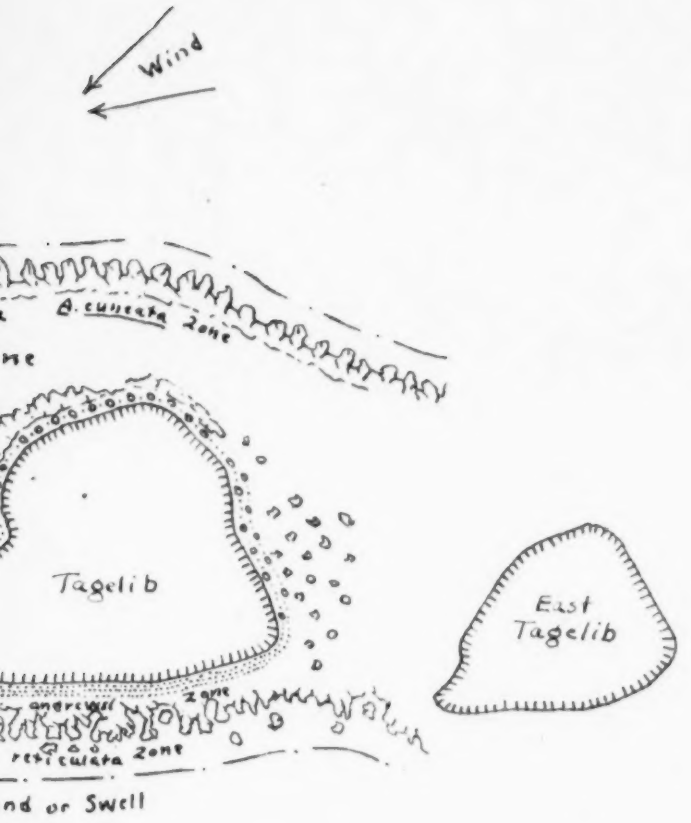
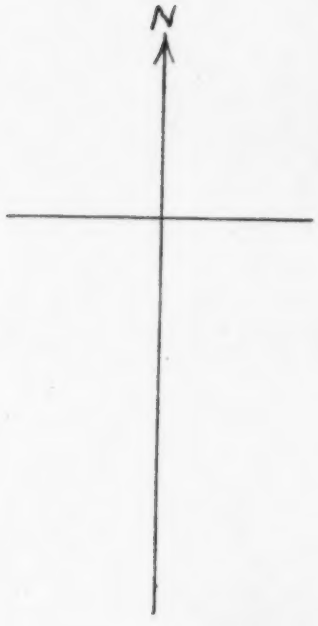


FIGURE 4. DETAIL MAP, NORTH HORN, ARNO. 1:8000.

FIGURE 5. DETAIL MAP, TAKLEB I., ARNO.





1 MILE

0. 1:8000.

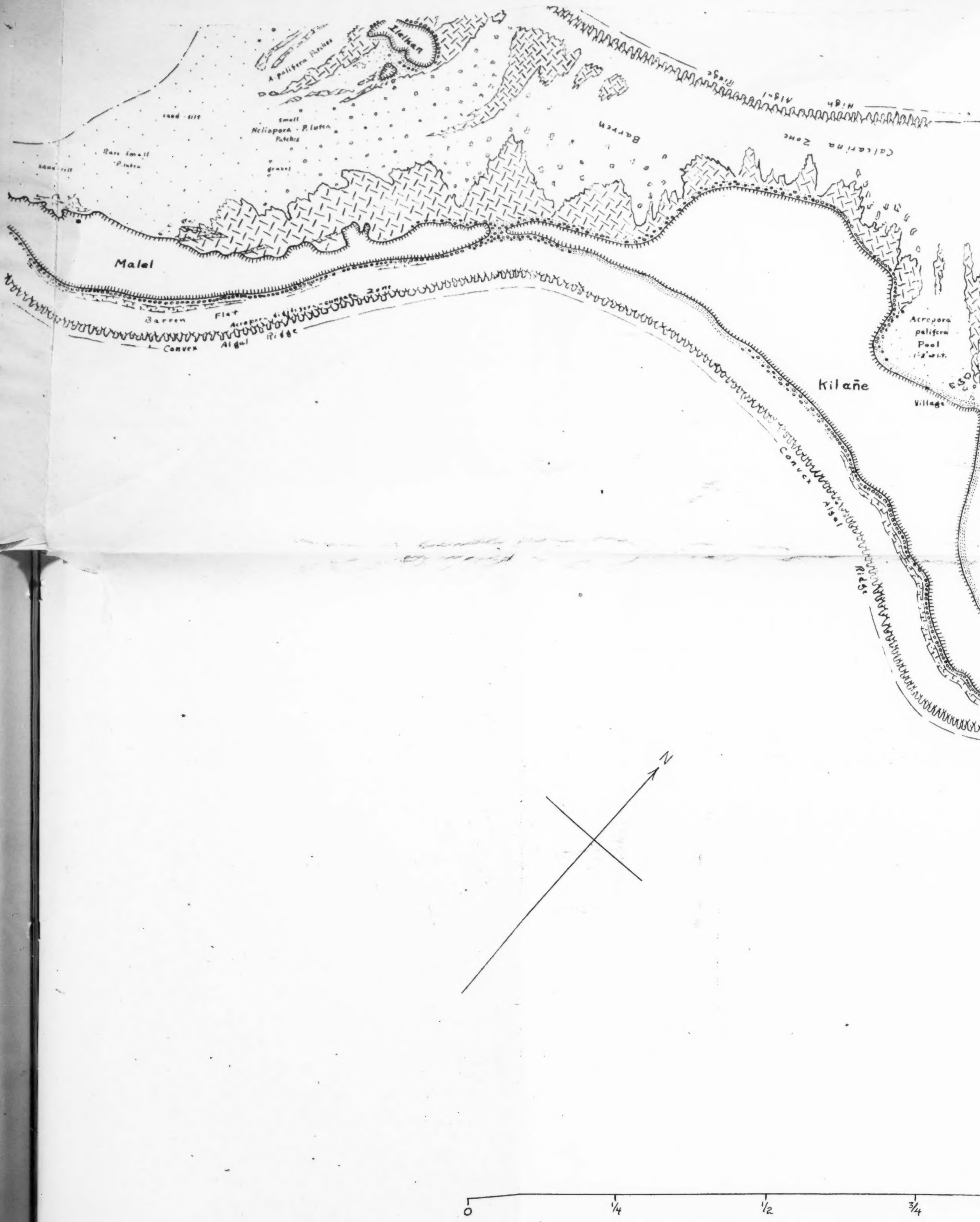


FIGURE 6. DETAIL

Mixed Coral Beaches

Village

Tinak

1

2

MILES

L MAP, EAST HORN, ARNO. 1:8000.

Pass

2.5 km.

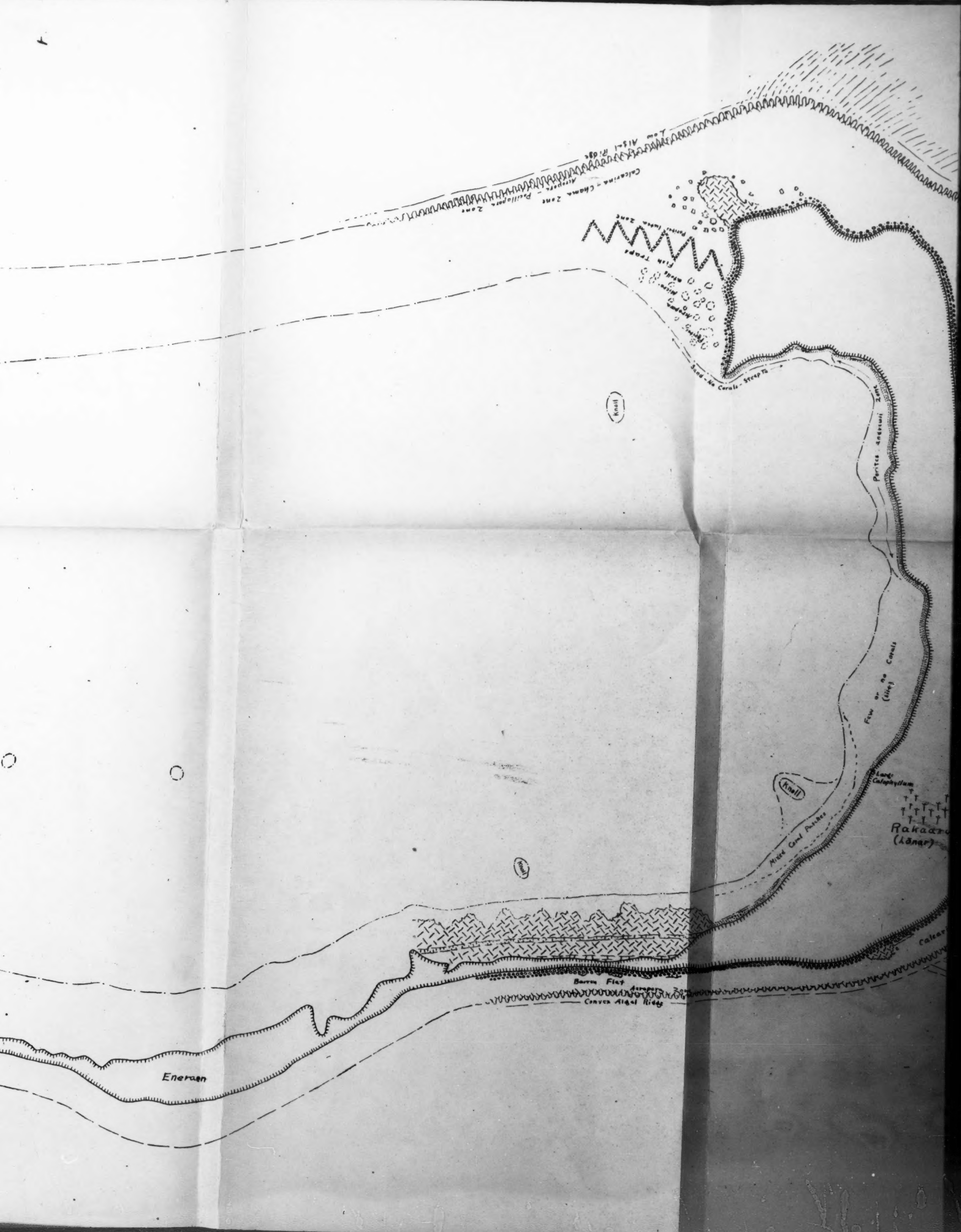
5 km.

10 km.

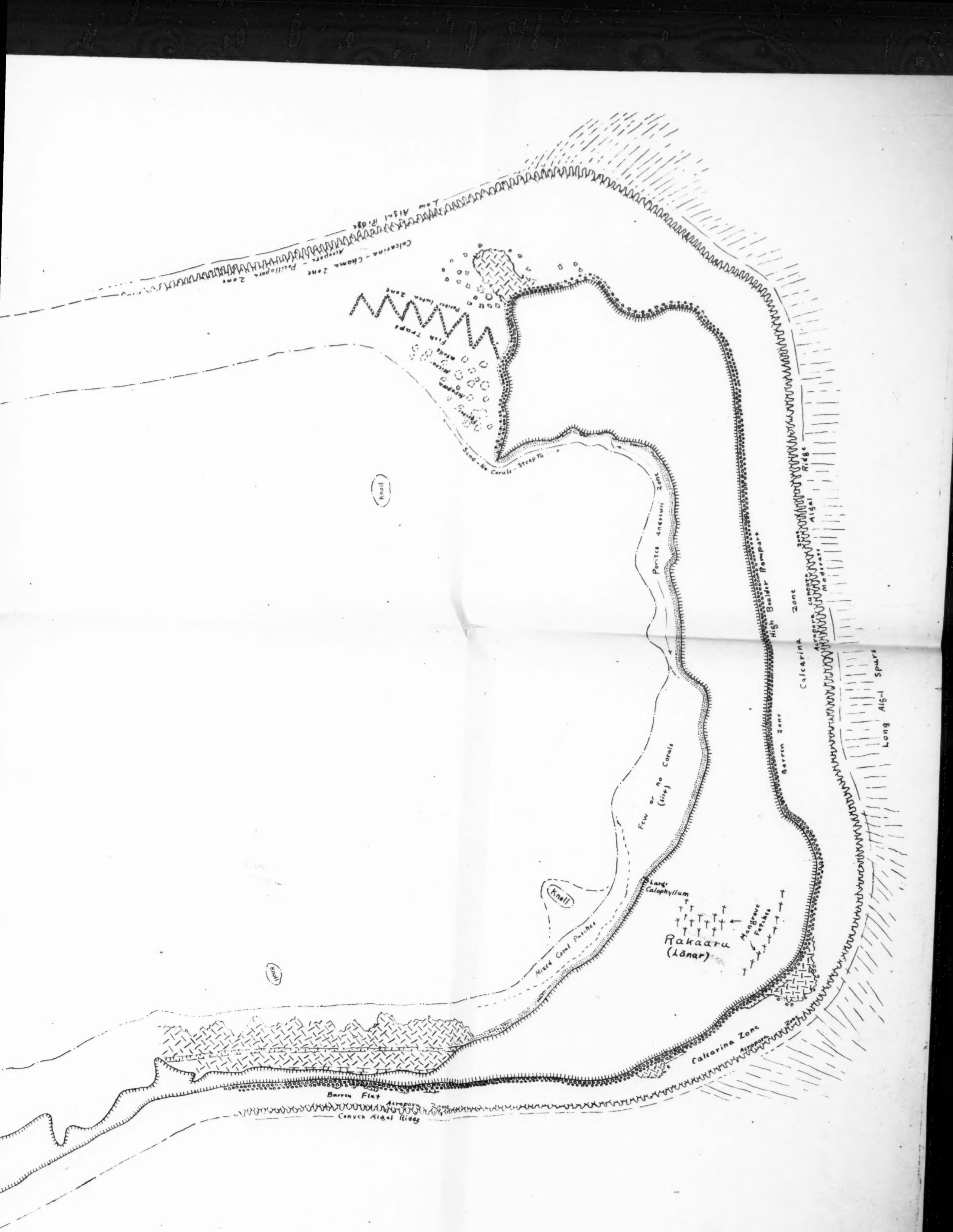
Village

Tinak

2


Calcarina - Chama Zone
Acropora - Pocillopora Zone
Reef Flat
Low Algal Ridge
Seaward Slope
Fish Tropa
Porites lutea Zone
Knoll
Sand - No Corals - Steep Ta
Porites andrewsi Zone
Few or no Corals (Live)
Knoll
Mixed Coral Patches
Knoll
Barren Flat
Acropora Zone
Convex Algal Ridge
Eneraen

Pass
25m.
50m.
100m.
Village
Tinak
Eneraen


Calcarina - Chama Zone
Acropora - Pocillopora Zone
Algal Ridge
Low Algal Ridge
Sand - No Corals - Steep To
Knoll
Porites andrewsi Zone
High Boulder Rampart
Calcarina Zone
Acropora Zone
Algal Ridge
Moderate
Algal Spurs
Long
Few or no Corals
(silt)
Barren Zone
Knoll
Large Calophyllum
Rakaaru
(Lonar)
Mangrove Patches
Mixed Coral Patches
Knoll
Calcarina Zone
Acropora Zone
Barren Flat
Convex Algal Ridge

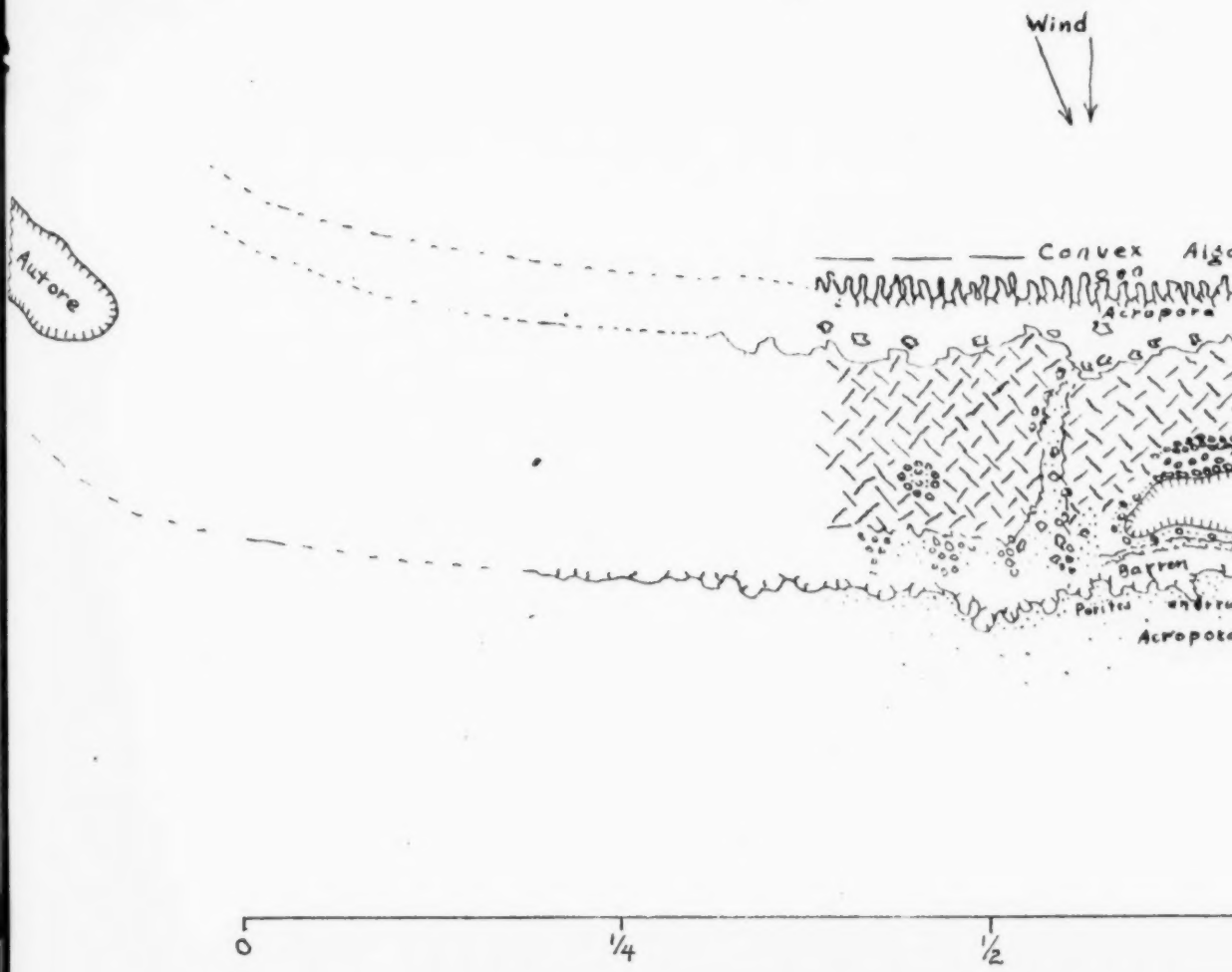
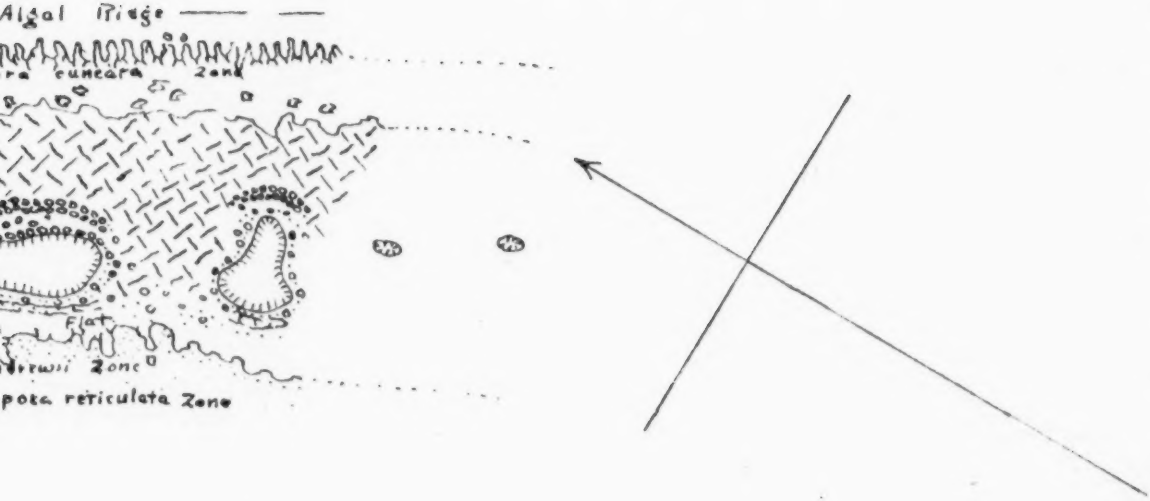
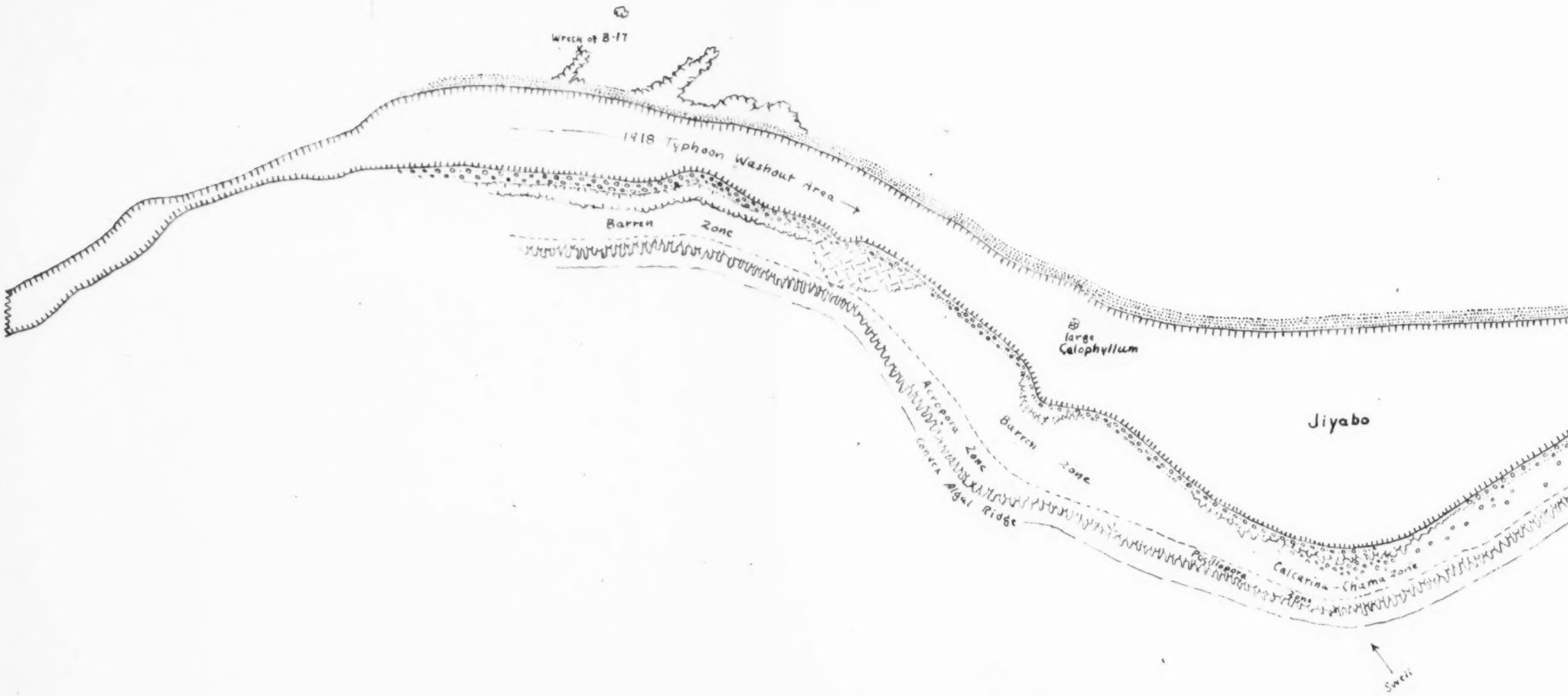


FIGURE 7. DETAIL MAP, SOUTH OF AOT



1 MILE

OTLE. 1:8000.


Wreck of B-17
1918 Typhoon Washout Area
Barren Zone
large Calophyllum
Jiyabo
Acropora Zone
Barren Zone
Coral Algal Ridge
Porites Zone
Calcarina - Chama Zone
Swell
1

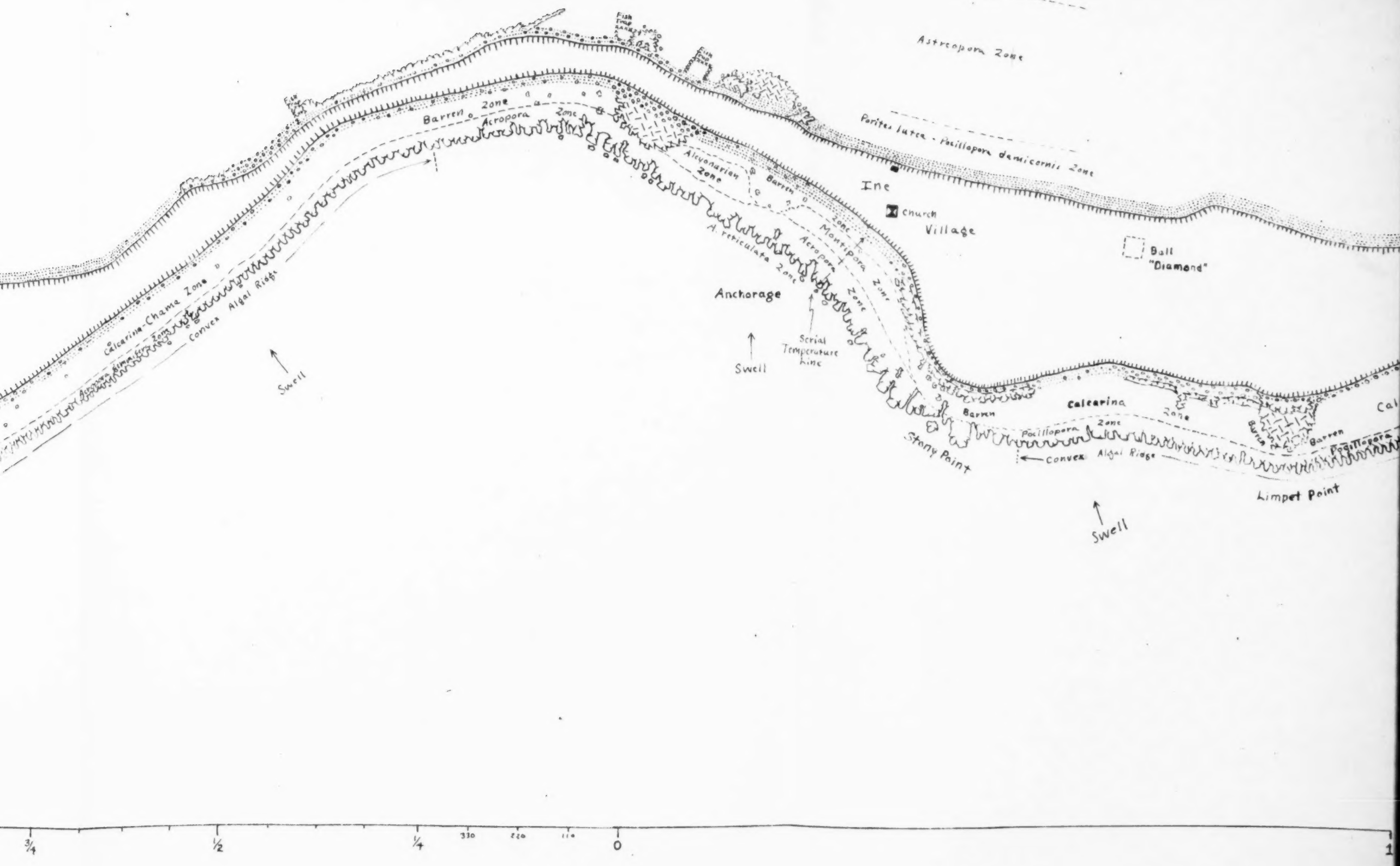


FIGURE 8. DETAIL MAP, PART OF INE I., ARNO. 1:8000.

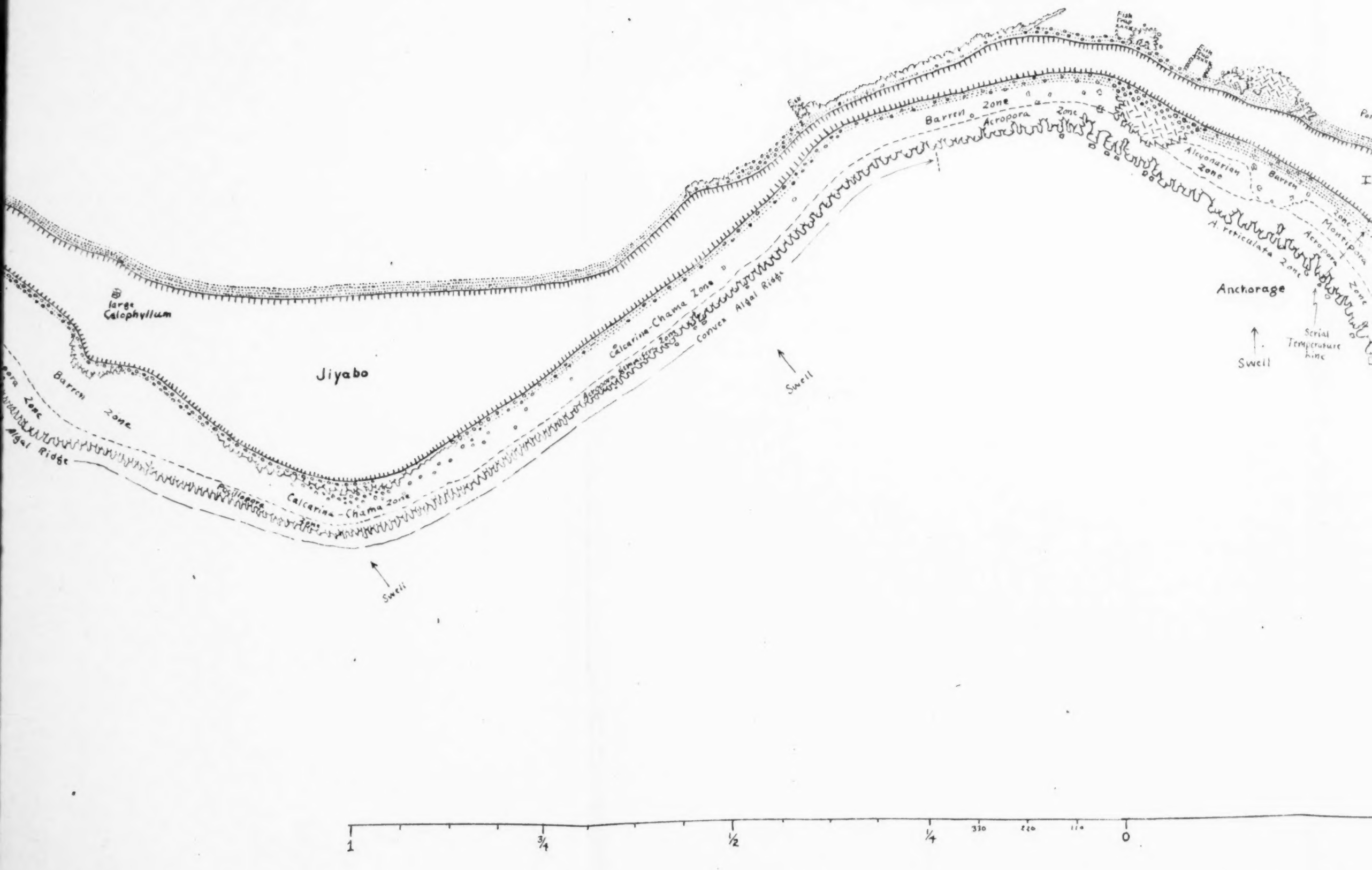
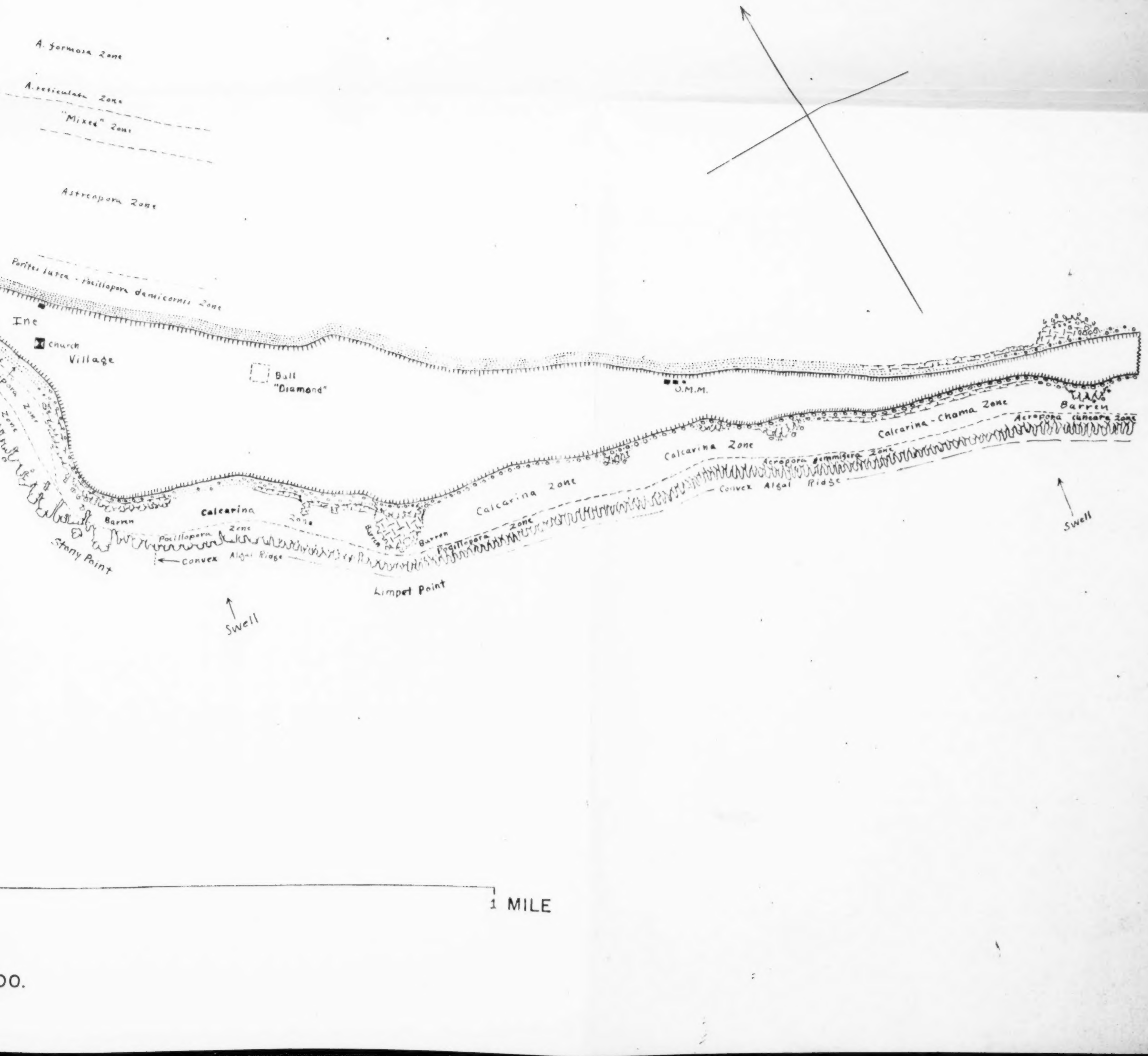


FIGURE 8. DETAIL MAP, PART OF INE I., ARNO. 1:8000


A. formosa Zone
A. reticulata Zone
"Mixed" Zone
Astreopora Zone
Porites lutea - Pocillopora damicornis Zone
Ine
church
Village
Ball
"Diamond"
O.M.M.
Barren
Acropora cuneata Zone
Calcarina - Chama Zone
Acropora brammigera Zone
Calcarina Zone
Convex Algal Ridge
Swell
Calcarina
Zone
Barren
Pocillopora Zone
Convex Algal Ridge
Stony Point
Limpet Point
Swell
1 MILE

OO.

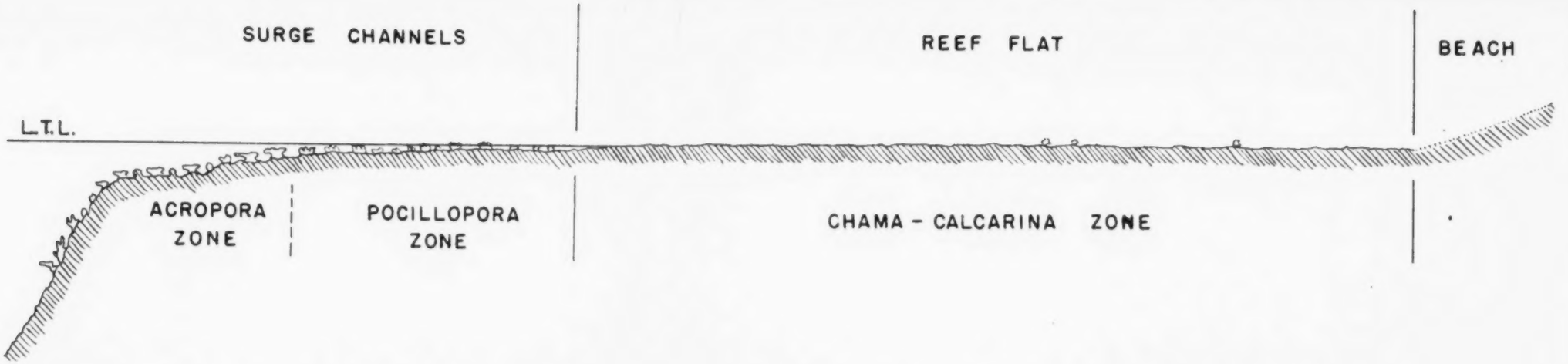


FIGURE 9. SEAWARD REEF, TYPE IA, INE I.

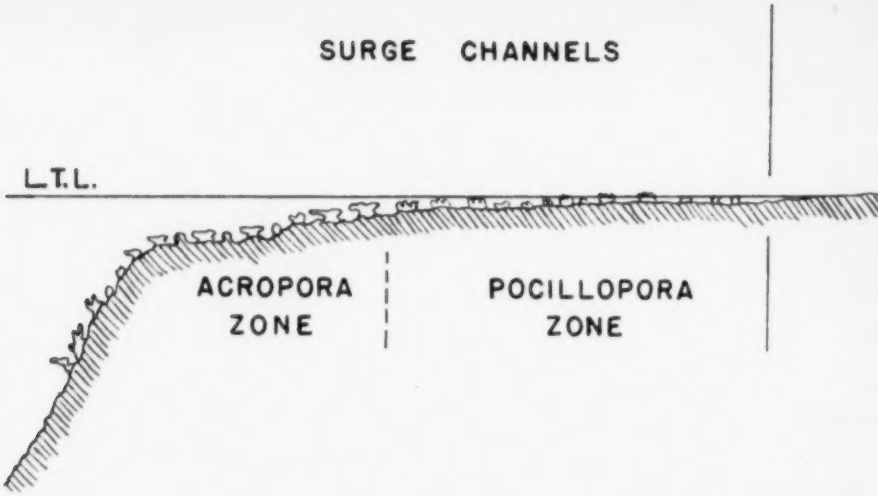
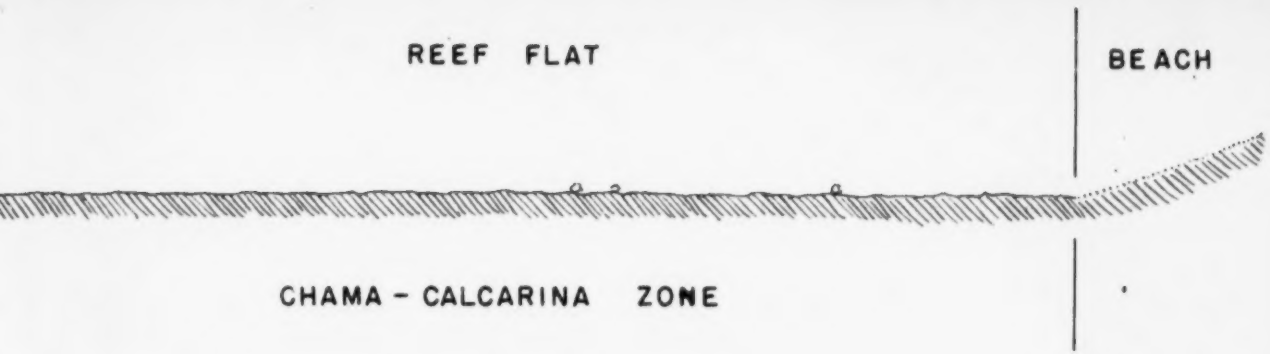


FIGURE 9. SEA



EAWARD REEF, TYPE IA, INE I.

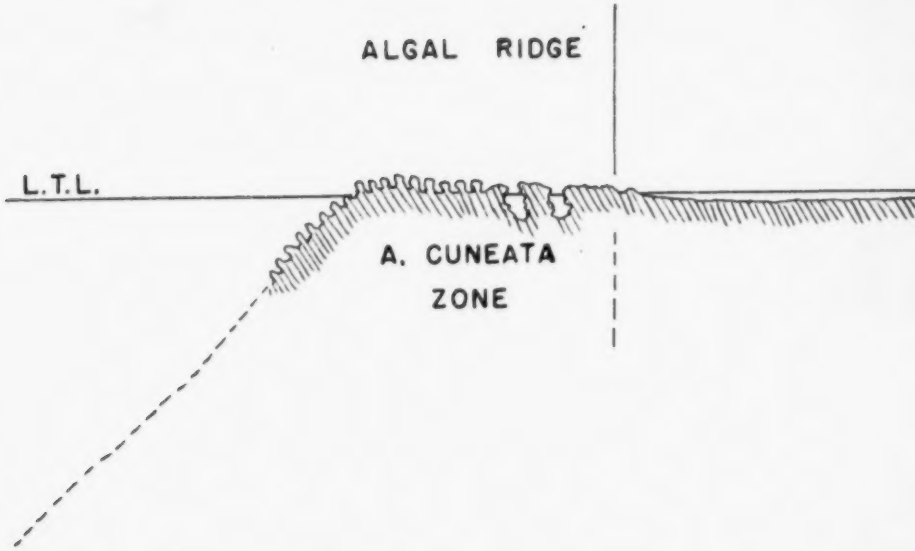
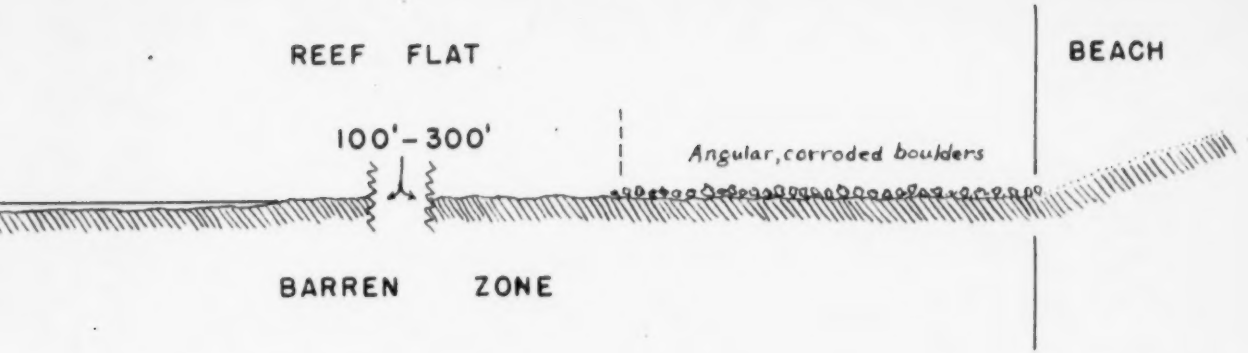


FIGURE 10. SEAW



EAWARD REEF, TYPE 1B, TAKLEB I.

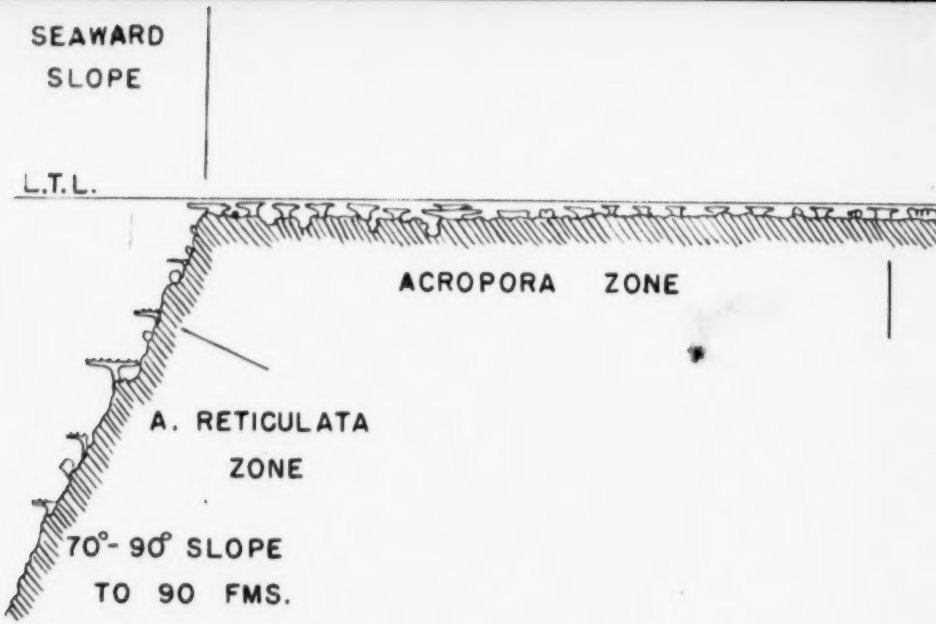
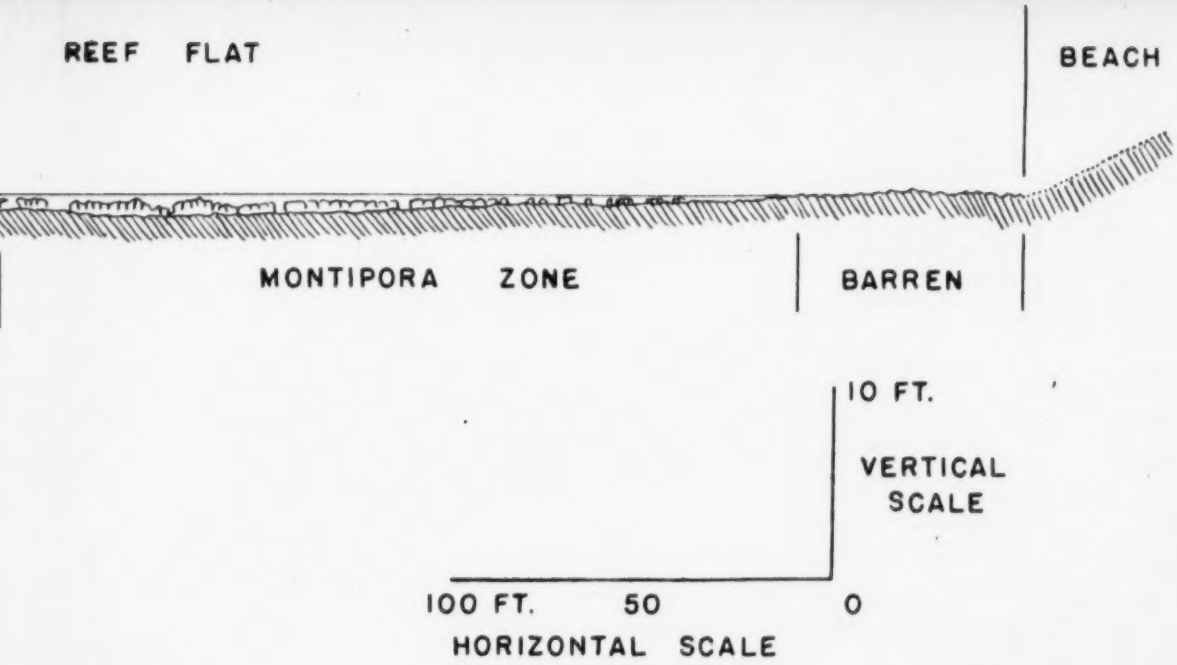
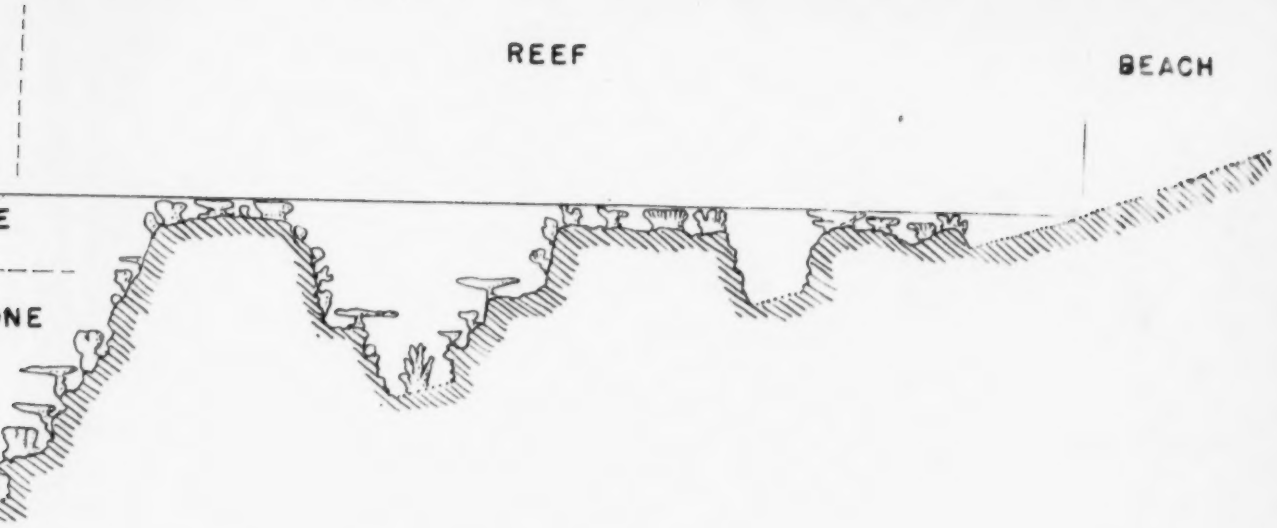


FIGURE 11. SEAWARD REEF,



TYPE IIA, INE ANCHORAGE.

FIGURE 12. LAGOON



N REEF, LEEWARD TYPE, TAKLEB I.

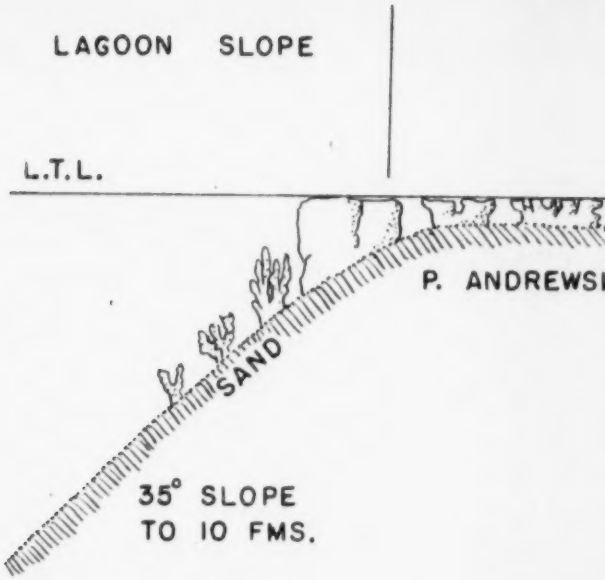
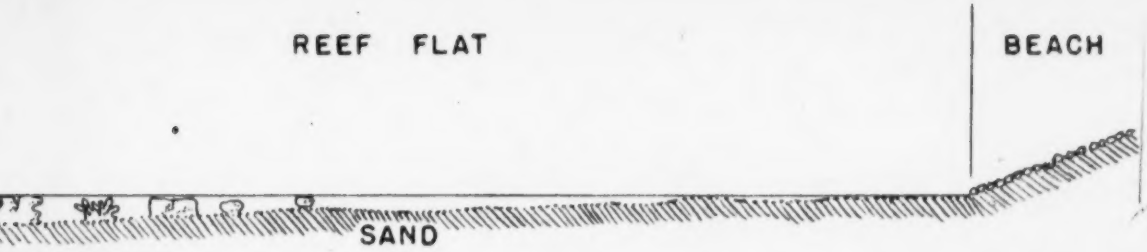


FIGURE 13. LAGOON REEF, ENCLOS



OSED LAGOON, NORTH HORN.

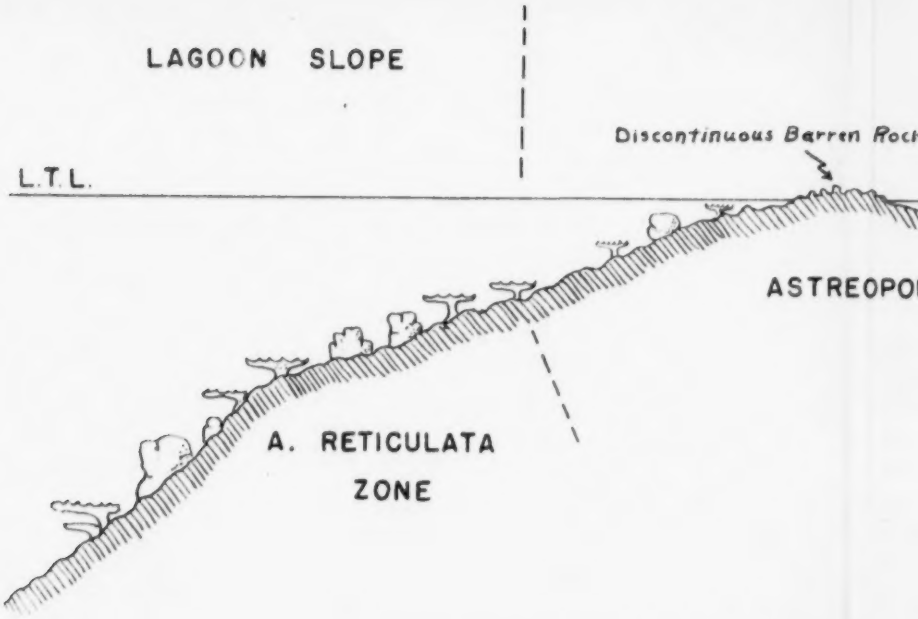
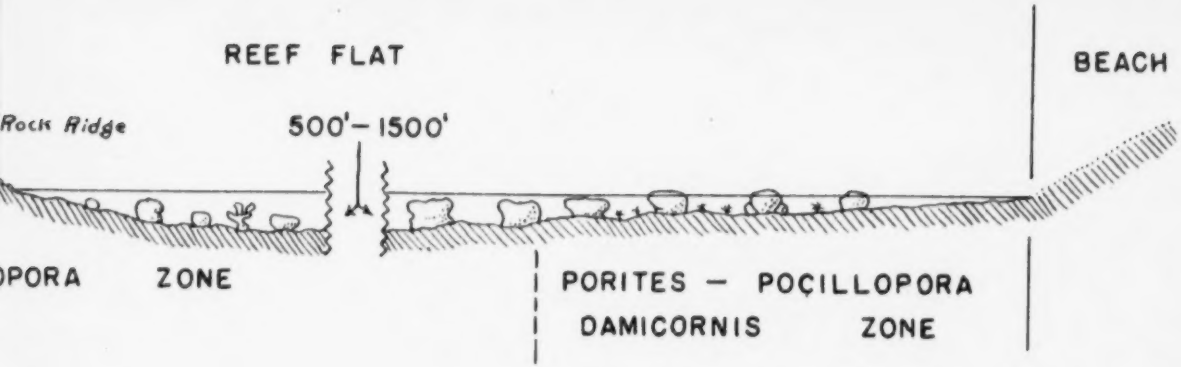
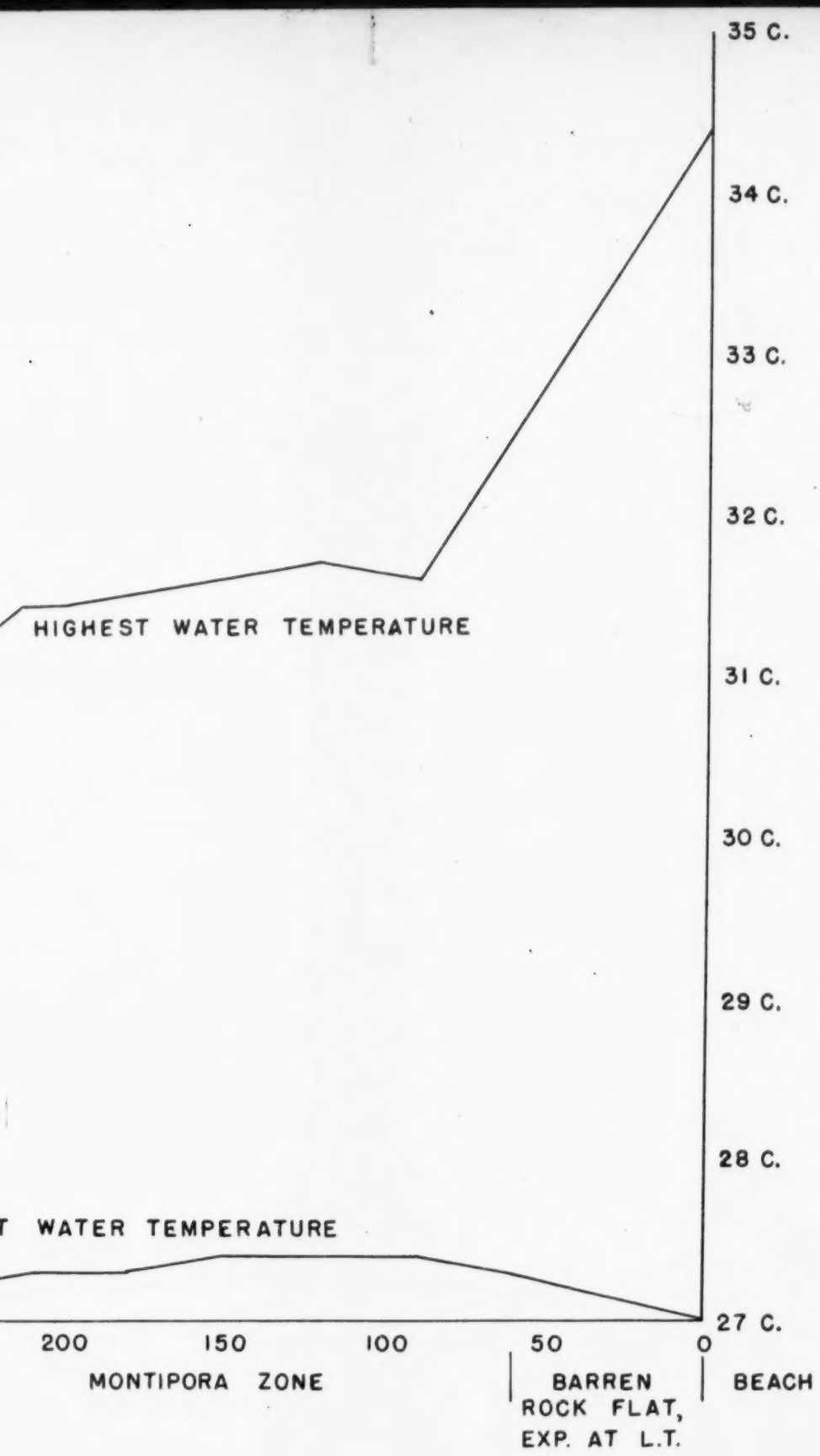


FIGURE 14. LAGOON REE



EEF, WINDWARD TYPE, INE I.

FIGURE 15. WATER TEMPERATURES ACROSS



SS INE ANCHORAGE REEF, JUNE, 1950.

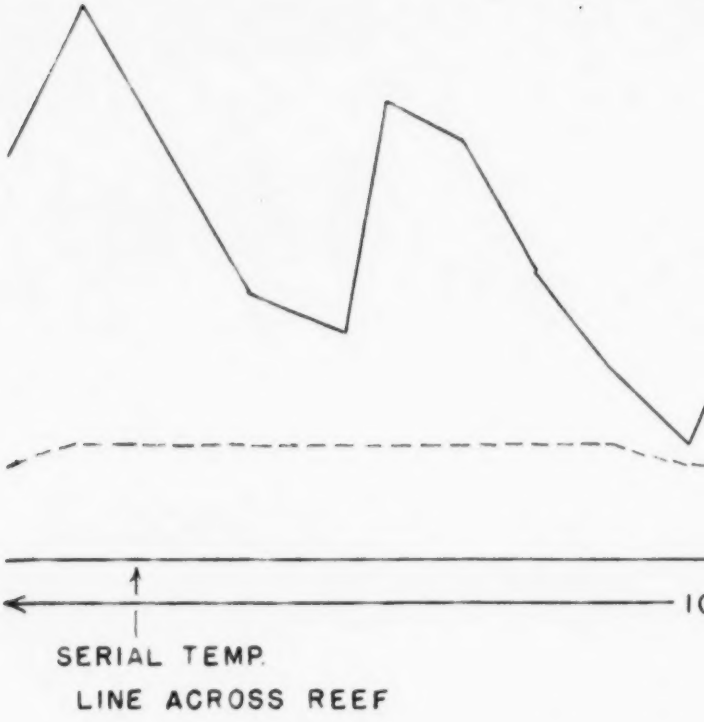
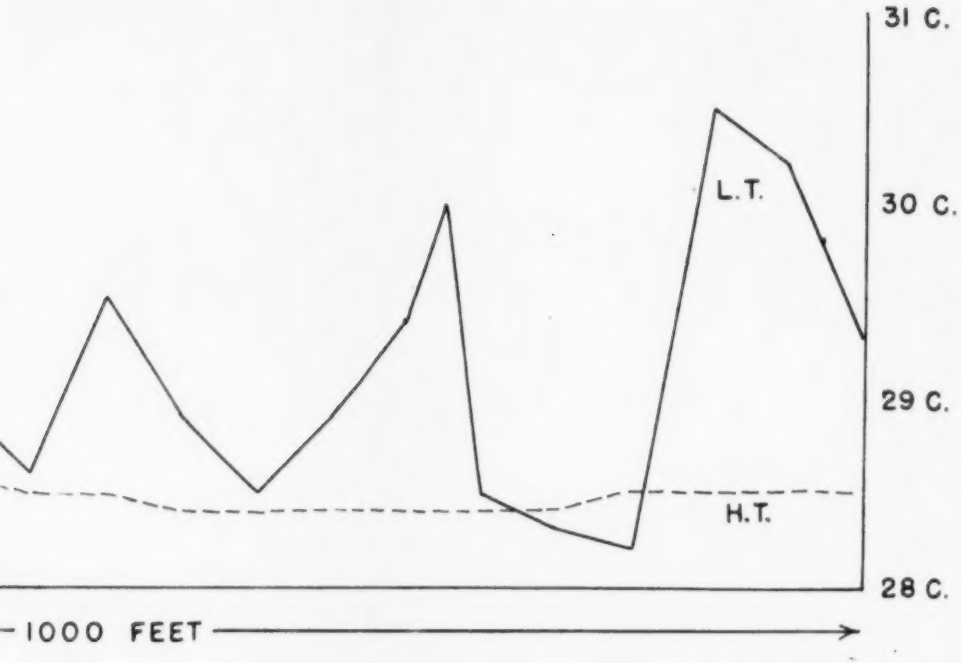


FIGURE 16. WATER TEMPERATURE
EDGE OF



RES ALONG INE ANCHORAGE REEF, INNER
F ACROPORA ZONE.